

A MULTIVARIABLE ATMOSPHERIC
DISPERSION MODEL

By

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A MULTIVARIABLE ATMOSPHERIC DISPERSION MODEL

by

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A computer-solved atmospheric dispersion model was developed to assess the effect of gaseous pollutants emitted from multiple areal and point sources. The model accounts for the effects of wind speed and direction, atmospheric stability, and source emission rate. These factors can be averaged over any integral multiple of an hourly period from 1 to 24 hours. The output parameter is the ground level contaminant concentration computed for 225 receptors defined by a 15- by 15-mile grid. The time scale of the output parameter can be any integral multiple of an hourly period.

The ground level concentration was considered to be the resultant effect of the emissions from areal sources, the emissions from point sources, and the airborne pollutant one time period after emission. These effects were determined

by the Gaussian dispersion equation and modifications thereof. Other features of the model are: (1) the wind speed is considered a logarithmic function of height, (2) the plume rise is considered to be a function of downwind distance and is limited by discontinuities in the vertical stability structure, (3) only the receptors within the downwind range of a source, as determined by the product of wind speed and travel time, are affected by emissions from that source, (4) the dispersion parameters σ_y and σ_z are estimated by mathematical equations, and (5) pollutant decomposition is accounted for by an exponential decay function.

The model was tested using data collected as part of the Greater Jacksonville Air Pollution Control Program. The data included hourly averages of wind speed, wind direction, and vertical temperature measurements. The latter were made at the ground, 100-, 200-, 300-, 450-, and 750-foot levels of a television tower. A sulfur dioxide emission inventory for December, 1965, and January, 1966, was compiled for the one-mile square areas defined by the grid system and for major point sources. The computed ground level concentrations were compared with the monthly sulfation pattern and observed 24-hour concentrations from 11 sampling stations.

Of the 111 24-hour concentrations compared, representing 12 days, 95 percent were with ± 1 pphm, 4 percent were high by more than 1 pphm, and 1 percent were low by more than 1 pphm. This accuracy is significant at the 99 percent level when tested by the chi square test. Several applications of the model are also illustrated.

The model is programmed in FORTRAN II compatible with the IBM 709 computer. Depending upon the time scale selected and the amount of data to be processed, the time required to make the computations for a 24-hour period varied from 15 to 30 minutes.

The results from this model demonstrated that dispersion models are practical and effective and that, if used judiciously, they could be of great value in many phases of an air pollution program.

CHAPTER I

INTRODUCTION

The Air Pollution Problem

Some of the effects of air pollution have been realized for quite some time but, until relatively recent times, they have either not been acute or have been considered the price of an industrialized society.

Records from ancient Rome have told of the Patri-cians grumbling because smoke smudged their togas, and early Spanish explorers made what is probably the first report of the Los Angeles area smog problem, which was, at that time, caused by Indian fires (1). In these early periods of history, however, the amount of airborne contaminants generated by the activities of man was relatively small when compared with the capacity of the atmosphere to receive and disperse this material. Thus at that time air pollution was only a nuisance or, at the most, an extremely localized problem.

As time progressed, so did the activities of man. Industrialization drew people together -- people to serve industry and people to serve the needs of other people. The result was urban areas of the magnitude we know today and an increasingly complex air pollution problem.

As early as the fourteenth century, air pollution, caused by coal smoke and gases, became enough of a problem in England to evoke a royal protest (2). From this time until the middle of the twentieth century, the air pollution problem became more and more acute, but little was actually done to alleviate the condition.

The hazardous effects of air pollution were dramatized very tragically in 1948, when twenty persons were killed and several hundred were made ill in an industrially caused incident in Donora, Pennsylvania, and again in December, 1952, when a smog condition in London caused the death of some four thousand persons. These events, probably more than anything else, aroused the public's interest in air pollution and stimulated the study of this malady.

The study could be resolved into two major parts -- a study of the contaminants and a study of the factors resulting in their dispersion. A fairly accurate quantitative

determination of several of the contaminants could be made analytically. However, very little was known about the factors affecting their transport. The assessment of these factors demanded a knowledge of atmospheric transport and dispersion. Although there were formulas available at this time (3,4) to describe atmospheric dispersion, they were not well substantiated because of a lack of sufficient empirical data (5).

Review of the Literature

Historical

The pioneers of atmospheric dispersion studies (6,7) directed their attention toward expanding the Fickian theory of molecular diffusion and then applying it to the atmosphere. According to the Fickian theory, the flux of a diffusing substance in a direction x is proportional to the concentration gradient in that direction, or, in formula

$$F = -D \frac{dc}{dx}.$$

Taylor (6) and Richardson (7) found that atmospheric dispersion could be described with this expression by using values of D of the order of 10^3 to 10^5 square

centimeters/second. These values were larger than values of D for molecular diffusion by a factor of 10^4 to 10^6 (4). It soon became evident to these workers that a universal value for D did not exist. Sutton (3), in one of the classic contributions to atmospheric dispersion formulation, proposed the hypothesis that the Fickian theory was not valid in atmospheric dispersion because it did not take into account the variation in turbulent eddy size. His work was based on a statistical theory developed by Taylor (8). Sutton assumed that the concentration density of a dispersed material in the horizontal and vertical crosswind directions was distributed according to the Gaussian distribution, and he defined his diffusion parameters in terms of the standard deviation of that distribution. The standard deviation was of the form

$$\sigma = \sqrt{\frac{1}{2}C^2x^{2-n}}$$

where

σ = the standard deviation of the distribution,

C = the virtual dispersion coefficient,

x = the downwind distance, and

n = a parameter which is a function of the vertical wind profile.

Using data available at the time, Sutton defined only one dispersion coefficient, but speculated that the diffusion rates in the vertical and horizontal directions might not be equal. If this were the case, the dispersion coefficient C would be the product of a coefficient for vertical dispersion and one for horizontal dispersion; i.e.,

$$C^2 = C_z C_y.$$

Also, the dependence of Sutton's dispersion parameter upon the downwind distance instead of upon time, as the Fickian theory prescribed, overcame another shortcoming of the earlier theory. This was the failure to recognize that the turbulent eddies responsible for instantaneous dispersion of a plume increased in size as the downwind distance increased; the most effective dispersion being caused by eddies of the same size as the plume cross-section.

The formula Sutton proposed for determining the ground-level concentration of a material emitted from a continuous point source was

$$X = \frac{Q}{\pi C_y C_z u x^{2-n}} \exp \left[\frac{1}{x^{2-n}} \left(\frac{y^2}{C_y^2} + \frac{z^2}{C_z^2} \right) \right]$$

where, in general units of mass, length, and time,

χ = the ground-level concentration, m/l^3 ,

Q = the source emission rate, m/t ,

π = the constant $3.1415\dots$,

u = the wind speed, $1/\text{t}$,

x = the downwind distance, 1 ,

y = the horizontal crosswind distance, 1 ,

z = the vertical crosswind distance, 1 , and

c_z , c_y and n are as previously defined.

The units of the variables may be in any consistent set.

Sutton's assumption of the Gaussian distribution of the contaminant in the crosswind directions has been verified (9,10,11,12), and his formula is still used.

Bosanquet and Pearson (4) developed a similar formula in 1936. Using data that were unavailable to Sutton, they defined separate coefficients for vertical and horizontal dispersion, thus substantiating Sutton's thought that the two diffusion rates might not be equal. They found that the rate of vertical diffusion was generally less than the rate of horizontal diffusion and hypothesized it was due to the fact that vertical dispersion near the ground is suppressed by the earth's surface.

In 1947, Sutton (13,14) published an extension of his earlier work and the results of diffusion studies conducted at Porton, England. These studies were carried out under adiabatic lapse conditions, and the data consisted of 3-minute average concentrations determined over a travel distance of 100 meters. From these data, Sutton found

$$n = 0.25, \quad C_y = 0.21, \quad \text{and } C_z = 0.12 .$$

Sutton also described the vertical wind profile by the relationship

$$u = u_o \left(\frac{z}{z_o} \right)^{2/(2-n)}$$

where

u = the wind speed at any elevation, z ,

u_o = the wind speed at a standard elevation, z_o , and

n = a dispersion parameter dependent upon the vertical wind profile.

Beginning about 1952, several investigators began studying the many facets of atmospheric dispersion and related subjects, and there was rapid advancement along many lines.

General dispersion

Friedman (15) and Holland (16) were among the investigators of the early 1950's. Their studies involved the evaluation of Sutton's dispersion parameters for various conditions of atmospheric stability and also the relationship between these parameters and height above the ground. The results of their studies are summarized by Strom (17).

In 1955 a series of dispersion studies was conducted at the Round Hill Field Station in South Dartmouth, Massachusetts, by a team from the Massachusetts Institute of Technology (18). Sulfur dioxide was used as a tracer, and 10-minute samples were collected to a distance of 200 meters from the source. The terrain was fairly flat and the area was devoid of trees and scrub growth. This study led to a very extensive investigation of atmospheric dispersion during 1956 (10,19).

The study, Project Prairie Grass, was conducted over very level terrain at a site near O'Neill, Nebraska. Again, sulfur dioxide was used as the tracer and 10-minute samples were collected to a distance of 800 meters from the source. Some facts revealed by this study and the Round Hill study were (5,10):

1. There is a general correlation between horizontal concentration profiles at short travel distances and the frequency distribution of the azimuth wind direction.
2. Significant deviation from the assumed normally distributed concentration profiles does occur, especially in periods of instability, but the normal distribution is still the most functional distribution.
3. The increase in plume width occurs at a faster rate than an increase in plume height. This was considered a consequence of the suppressive effect of the earth's surface on the vertical movement of air.
4. There is significant correlation between the vertical and horizontal diffusion and vertical and horizontal variances in the wind. This fact has been verified by others (20,21).
5. The ground level concentration at a downwind distance x can be expressed by the simple power law

$$C \propto x^{-b}$$

where b is an exponent with a value between 0.5 and 2.5, depending upon atmospheric stability.

It was proposed that the variances in the wind and the parameter b replace the strictly empirical factors of Sutton (14) in dispersion equations. This resulted in the expression

$$\chi = \frac{Q}{\pi u x^b \sigma_a \sigma_e}$$

for concentrations along the plume center line where

σ_a = the variance in the azimuth wind direction,

σ_e = the variance in the vertical wind direction,

and the other factors are as previously defined.

Cramer (5,22) presented these factors in a form in which they could be used in equations such as the one above. The results calculated by the proposed equation were one-third to one-half the values predicted by Sutton's equation (14) but were in good agreement with results of other studies (20,21).

Another approach, based upon the Round Hill and Prairie Grass data, was to define a horizontal dispersion parameter σ_y in terms of b and σ_a and a vertical dispersion parameter σ_z in terms of b and σ_e . This was done by regression analysis of the data and presented by Cramer (23). Results obtained by using these parameters were very close to the results obtained with the original parameters.

In 1958, a major study was conducted by Stewart, Gale, and Crooks (21) using radioactive argon gas emitted from the Harwell BEPO reactor in England. This study was

quite significant because the tracer was emitted from a stack surrounded by buildings 8 to 16 meters high rather than from a source on open flat terrain. The dispersion formula used was the one of Sutton (14) and the coefficients were evaluated over a distance of 10,000 meters.

The significant findings of this study were:

1. The dispersion coefficients are greatly influenced by the mode in which the plume is discharged and the effects of local turbulence.
2. Lateral diffusion is greatly increased by mechanically induced turbulence.
3. Downwind from a built-up area, dispersion coefficients revert to "open-country" values.
4. The particular values of diffusion parameters, for describing dispersion in a built-up area, can apply only to a very localized area.

The results of several studies (19,20,21,24,25) were reviewed by Meade and Pasquill (26), and values were estimated for the plume height H and the angular plume width ϕ . Gifford (27) converted these values to values for \overline{C}_y and \overline{C}_z with the equations

$$\overline{C}_y = \frac{x}{2.15} \tan \frac{\phi}{z}$$

and

$$\sigma_z = \frac{H}{2.15}$$

where

x = the downwind distance in meters,

ϕ = the angular plume width in radians, and

H = the plume height in meters.

The value 2.15 is the number of standard deviations from the plume centerline to the point where the pollutant concentration is 10 percent of that at the plume centerline. This is the usual definition of the crosswind limit of the plume. Gifford's curves for σ_y and σ_z for various stability classes (27) and downwind distances are presented in Figure 1 and Figure 2.

The values Gifford determined for σ_y agreed well with later values presented by Singer and Smith (29).

Dispersion over rough terrain and urban areas

The effect of terrain features on atmospheric dispersion is evident from the wide range of values reported for dispersion parameters. Limited results of three studies conducted over widely differing terrain are presented in Table 1 to illustrate the variation in these parameters. The parameters σ_y and σ_z presented by Gifford

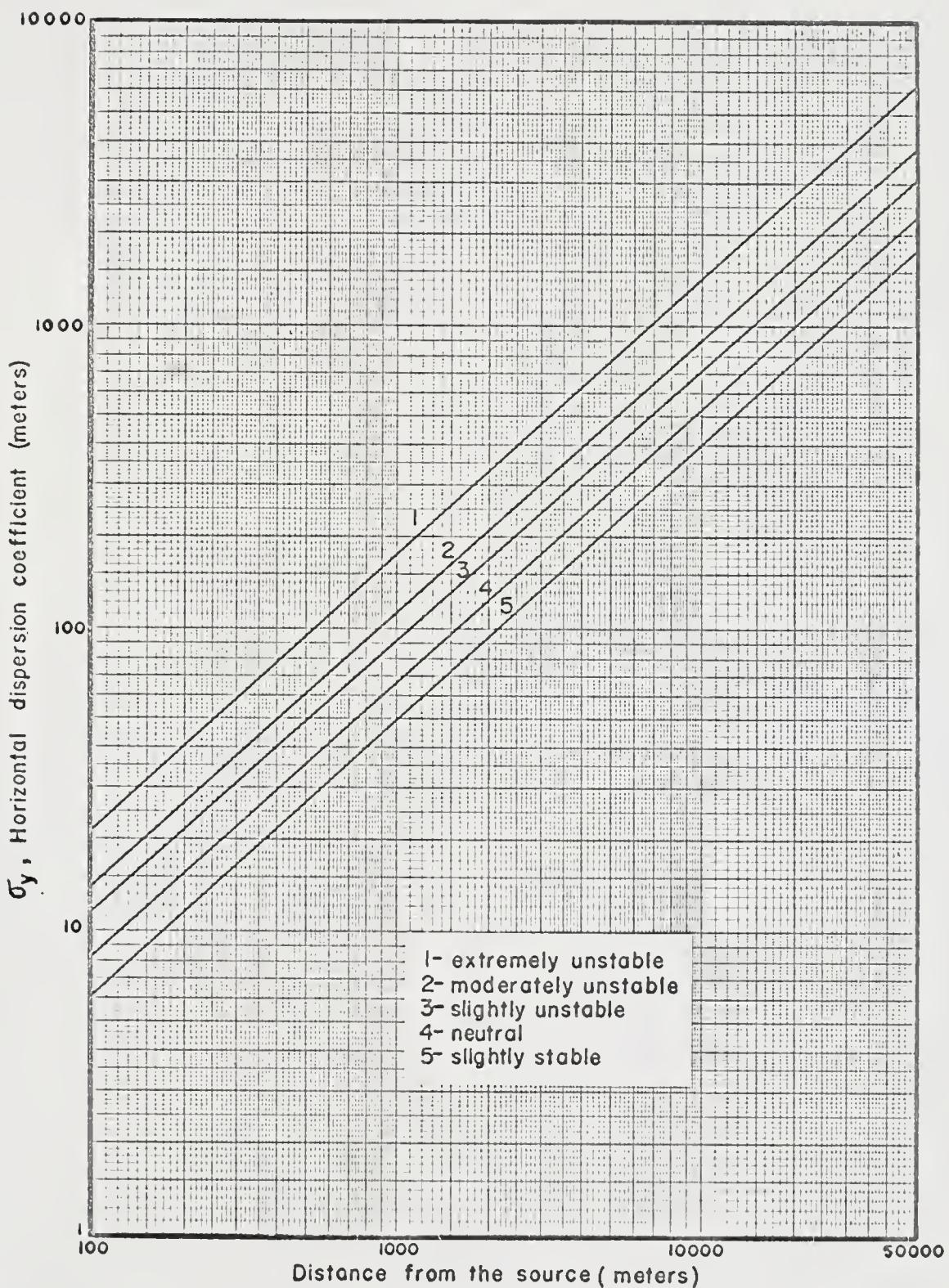


FIGURE 1-HORIZONTAL DISPERSION COEFFICIENT AS A FUNCTION OF DISTANCE FROM THE SOURCE

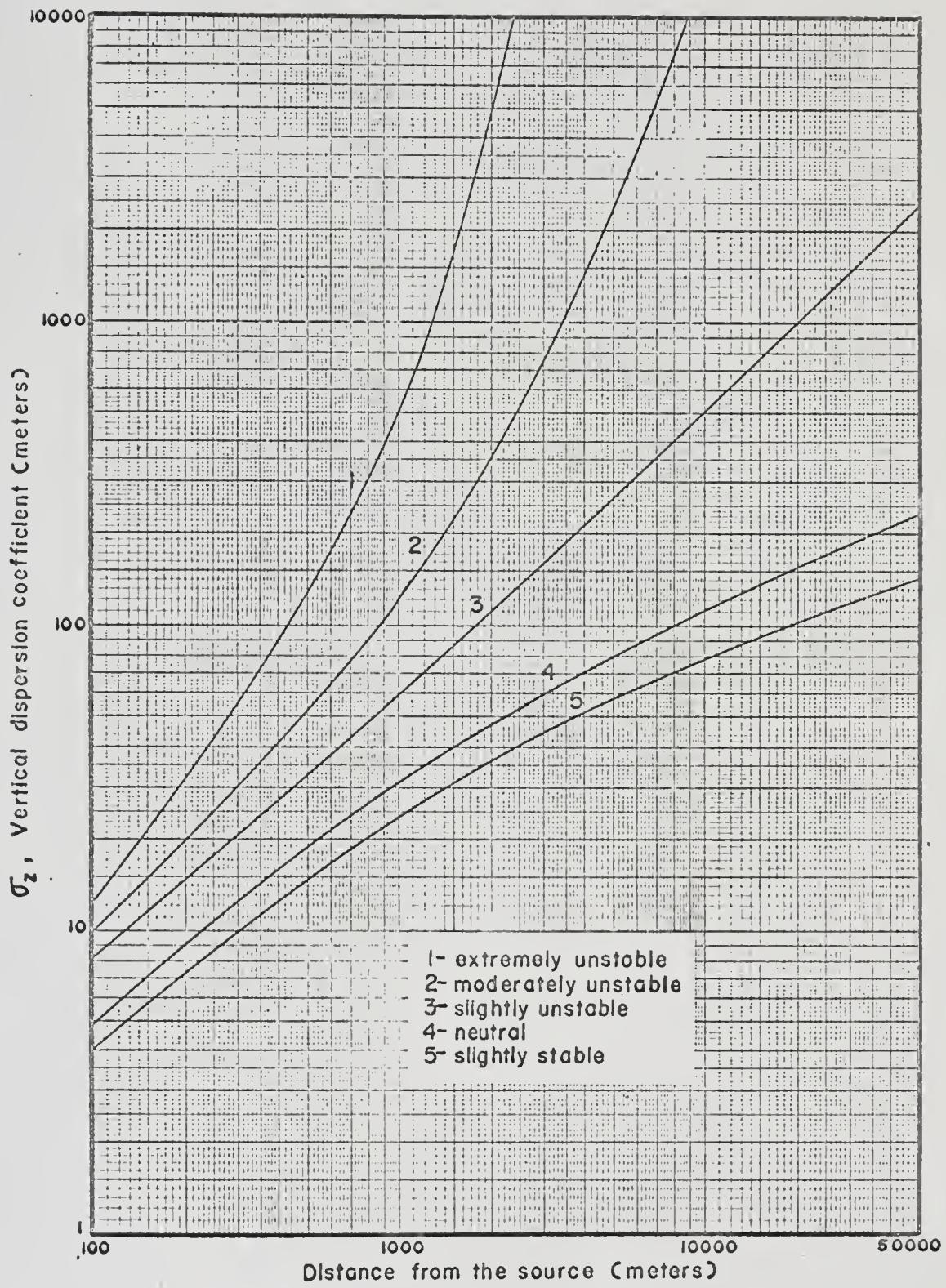


FIGURE 2 - VERTICAL DISPERSION COEFFICIENT AS A FUNCTION OF DISTANCE FROM THE SOURCE

TABLE 1

EFFECT OF TERRAIN ROUGHNESS ON ATMOSPHERIC
DISPERSION PARAMETERS

Investigator	Stability Condition	Parameter		
		n	C _y	C _z
Sutton* (14)	unstable	0.20	0.21	0.21
	neutral	0.25	0.12	0.12
	stable	0.33	0.08	0.08
Singer [†] (29)	unstable	0.19	0.56	0.58
	neutral	0.28	0.50	0.46
	stable	0.45	0.45	0.32
Stewart [‡] (21)	unstable	0.25	0.46	0.25
	neutral	0.25	0.46	0.20
	stable	0.25	. .	0.11

*Study conducted over smooth terrain.

[†]Study conducted over flat terrain with scrub growth and 8-10 meter trees.

[‡]Area within 500 meters of the source contained several buildings 8-16 meters high.

(27) agreed quite well with values of σ_y and σ_z that Singer and Smith (29) reported as being equivalent to their values of C_y , C_z , and n .

The selection of a set of parameters to describe dispersion at a particular site is entirely an empirical problem. The parameters must be selected to give computed results which agree with observed concentrations. Once parameters have been selected, however, they can be used with a reasonable degree of certainty. But, even with the most ideal set of parameters, Strom (17) and Smith (30) have both reported that large deviations from computed concentrations will exist because of local disturbances. This is especially true if one set of parameters is used over a large and heterogeneous area. Dispersion around isolated and areal disturbances has been studied by several investigators. Halitsky (31) reported that turbulence near buildings existed to a height of about twice the building height. The effect of this turbulent zone upon the dispersion of an airborne material will depend upon the level at which the material is emitted. This can be considered in three levels (32):

1. Street Level -- Diffusion is the effect of wind channeling between buildings and is generally upward.

2. Roof Level -- Diffusion occurs in all directions.
3. Elevated Sources -- Dispersion from these sources approaches nonturbulent, but as the dispersed material diffuses toward the ground, it is affected by turbulence in the lower zones.

The result of this turbulent mixing is a fairly uniform concentration gradient up to twice the height of the disturbance. Davidson (33) has studied the turbulence induced by a geographical ridge and has found the turbulent zone to exist between one-half the elevation of the ridge line and slightly above the ridge line, depending upon atmospheric stability. The lower turbulent zone corresponded to an unstable lapse condition and was much more intense than the turbulence existing under inversion conditions.

The wind is the major cause of turbulence near local interferences (34), but in urban areas the vertical and horizontal temperature gradient is also a factor. Studies (35,36,37) have shown that cities function as a heat sink; i.e., they absorb more heat from solar radiation during the day than surrounding nonurban areas do. At night this heat, along with heat generated by normal activities within the city, is radiated to warm the air

directly over the city. This phenomenon maintains the air over the city in an unstable state a large part of the time, thus increasing turbulence. The effect is most pronounced at night and is slight to nonexistent during the day.

Another effect of the elevated nocturnal urban temperature is that cool air from the suburbs will flow radially inward toward the center of the city, forcing the warm air at the center upward. This also increases turbulence.

Panofsky and Townsend (38) have examined the wind profile on the lee side of an urban area and have found that it returns to an "open country" profile in a distance equivalent to about twenty building heights. This corresponds to a slope of the turbulent boundary layer of about 1:10. This phenomenon was also observed in the dispersion studies at Harwell (21).

The effect of sampling time on dispersion parameters

Sutton (13,14) first recognized the effect of sampling time on the values obtained for dispersion parameters in the Porton study. It was observed that short-term peak concentrations were generally higher than longer-term averages.

Hilst (39) gave the reason for this very concisely. When the effluent material is averaged over a period of time, it is normally distributed about the plume centerline with a mean \bar{X} , a horizontal crosswind variance σ_y^2 , and a vertical crosswind variance σ_z^2 . This concentration is averaged about the moving centerline of the plume, which is normally distributed about the mean wind direction with a variance σ_n^2 . Thus, a short-term sample taken from an instantaneous position within the plume will have a horizontal crosswind variance of essentially σ_y^2 and will indicate a higher concentration than a long-term sample because the variance of the latter sample is the sum of σ_n^2 and σ_y^2 .

Studies of the peak to mean ratio for various sampling times were made on results collected during the Prairie Grass project (22) and at Harwell (21). These studies indicated that concentration is inversely proportional to the fifth root of time. Based on the results of oil-fog dispersion over a distance of 5,000 meters, Singer (40) arrived at a 1-minute peak to 100-minute mean ratio varying from 4 to 14, depending upon atmospheric stability. McCormick and Xintaras (41) related peak to mean concentrations for multiple sources and found the ratio smaller than the ratio for single sources. They reported 3-minute peaks

of 1.5 times the hourly average. The average results of these studies are summarized in Figure 3.

Plume rise equations

The rise of plumes into the atmosphere is probably one of the most controversial subjects in atmospheric dispersion. Several equations (42,43,44,45,46) have been developed from both a theoretical and an empirical approach, but no one formula gives entirely satisfactory results. Strom (17) reviewed nine formulas that were in use in 1962 and concluded that Holland's formula (42) gave the highest values of ground level concentration, followed by the Thomas formula (43), the Bosanquet, Carey, and Halton formula (44), the Priestley formula (45), and Sutton's formula (46).

Stewart, Gale, and Crooks (21) compared plume elevations calculated by Bosanquet's formula with the observed plume rise at Harwell and found it to be 35 percent low at a distance of 1,000 meters. One reason for this is that Bosanquet's formula, as well as the others cited thus far, limits the maximum plume rise.

Schmidt (47) reported values of a correction factor P which were equal to the observed plume rise divided by

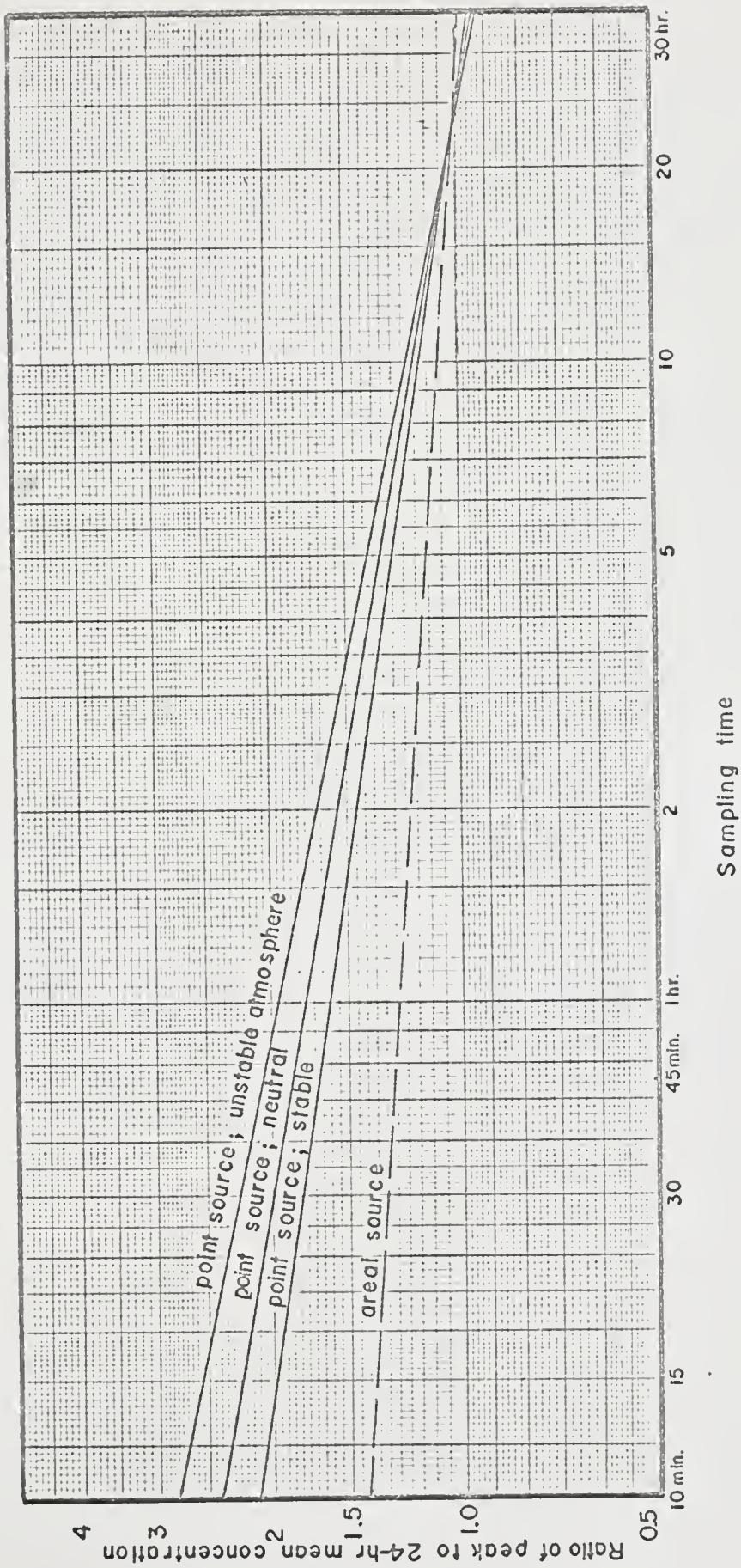


FIGURE 3 - EFFECT OF SAMPLING TIME AND STABILITY ON OBSERVED CONCENTRATIONS

the computed rise. Based on this factor, Holland's formula was superior to five others tested. The standard deviation of P for the Holland formula was 0.40, with P ranging from 2.055 to 0.420. The standard deviation of P for the other formulas was as high as 1.9.

In the same paper, Schmidt developed a plume rise equation which took into account the vertical temperature gradient, a factor not included explicitly in previous formulas. Neither did Schmidt limit the rise of the plume in an unstable atmosphere. He stated that under such conditions a plume would theoretically rise indefinitely.

Briggs (48) extended a formula which was developed by Scorer (49) to include the vertical temperature gradient and arrived at an expression comparable to that of Schmidt. Briggs concluded that during the transitional rise the plume height is proportional to the two-thirds power of the downwind distance. Unfortunately, neither the formula developed by Briggs or by Schmidt is well suited for use in a large-scale dispersion model because of their complexity.

The equations just considered have been for the rise of plumes from fairly large sources and can not be used to describe the rise of a plume from a single dwelling. Lucas (50), however, presented a formula based on a modified

version of Sutton's formula (46) to describe the rise of plumes from a large number of dwellings. The formula is

$$\Delta H = 5x \left(\frac{3}{u}\right)^3$$

where

ΔH = the plume rise in feet, and

u = the wind speed in feet/second.

This formula is applicable under all stability conditions, with the limitation that ΔH is limited to 50 feet in the case of a stable atmosphere.

A feature of the atmosphere that has been recognized for quite some time but that is rarely considered in dispersion calculations is the physical limitation on upward dispersion imposed by a stable layer aloft. Pasquill (51) mentioned this feature and suggested that it could be accounted for by limiting the maximum value of σ_z to a value equal to the height of the inversion base H , i.e.,

$$\sigma_z \text{ (max)} = H.$$

As a result of studies at Brookhaven, Singer and Smith (29) placed as a limit

$$\sigma_z \text{ (max)} = 1.5H.$$

They stated that Pasquill's assumption implied that some of the airborne contaminant penetrated the stable layer -- an unlikely occurrence. They also reported that the effect of placing a limit on G_z is apparent only at great distances downwind. As an example, the effect of an inversion base at a height of 500 meters would just become noticeable in the computed ground level concentration at a downwind distance of 9,000 meters.

Gifford (27) suggested that the limit on G_z be

$$G_z \text{ (max)} = 0.5H.$$

This assumption was based on a defined plume height of $2.15 G_z$.

Hosler (52) and Holzworth (53) have reported the frequency of inversions and the maximum mixing depth that might be expected over contiguous United States. Some of these data are present in Table 2.

Dispersion models

Several dispersion models have been developed to assess the effects of multiple sources of pollution on a receptor. These models have differed considerably in the time scale involved and the variables considered.

TABLE 2

MAXIMUM MIXING DEPTH IN THE ATMOSPHERE
OVER NORTHEASTERN FLORIDA (53)

Month	Max. Mix. Depth (meters)	Month	Max. Mix. Depth (meters)
Jan.	700	July	1,400
Feb.	900	Aug.	1,400
March	1,100	Sept.	1,300
April	1,300	Oct.	1,100
May	1,400	Nov.	900
June	1,400	Dec.	700

The most general models are those which consider all the sources within an area to be distributed uniformly as a line or as a band of finite width. These distributions are usually assumed to have an infinite crosswind length. Lucas (50) applied such a model to Leicester and London, England, using the seasonal average value of wind speed, wind distribution, and sulfur dioxide emission rate. The basis of the model was a numerically integrable form of Sutton's equation that Lucas derived. Limited results presented by Lucas agreed well with observed sulfur dioxide concentrations averaged over the same period. Some interesting facts brought out by Lucas' model were:

1. A maximum in the ground level concentration of a contaminant emitted from an areal source occurs with a wind speed of about 2 mph. For higher wind speeds, the contaminant is diluted by the wind. For lower wind speeds and a neutral or unstable lapse rate, the ground level concentration is reduced because of plume rise. During stable conditions, the concentration decreases as the wind speed drops below 2 mph because of limited plume rise. But, as the wind speed drops below 0.5 mph, the ground level concentration begins to build up rapidly.
2. A stable layer of limited height based at ground level results in a smaller ground level concentration than a stable layer of infinite height. This is especially true if the stack height approaches the top of the stable layer.
3. Within a uniformly distributed areal source, the ground level concentration builds up continuously from the windward edge of the source and reaches a maximum at the downwind edge of the source.
4. The ground level concentration drops off very rapidly beyond the downwind edge of an areal source.

Hilst (54) and Gasiorowski (55) have both developed similar models. Gasiorowski compared the relative effects of various stack heights and showed that the maximum ground level concentration from an areal source occurred with the lowest stack height and appeared slightly beyond the downwind edge of the area. As the stack height was increased,

the ground level concentration was decreased and the maximum appeared farther downwind.

A more refined model was designed by Mead and Pasquill (56) to describe the biannual sulfur dioxide concentration at a fixed distance from the center of Staythorpe, England. Their model related the sulfur dioxide concentration directly to the average monthly sulfur dioxide emission rate and the fractional distribution of the wind direction, and inversely to the mean wind speed. The correlation between concentrations computed with this model and observed concentrations was 0.604 for the winter months and 0.804 for the summer months.

A model was formulated along similar lines by Larson, Stalker, and Claydon (57) to describe the radial distribution of sulfur dioxide around Nashville, Tennessee. Their model showed a maximum concentration at the center of the city, with the concentration decreasing away from the center according to the proportion

$$S \propto \exp[-(\frac{r}{a})^2]$$

where

s = the sulfation rate,

r = the radial distance from the center of the city, and

a = an empirically determined constant.

Pooler (58), Clarke (59), and Turner (60) developed models based upon the basic dispersion equation

$$\chi = \frac{Q}{\pi u \sigma_y \sigma_z}$$

where

σ_y = the horizontal dispersion coefficient in meters,

σ_z = the vertical dispersion coefficient in meters,

and the other parameters are as defined previously.

Pooler subdivided the area to be incorporated in his model into 1-mile-square increments and assumed that all of the contaminants from each increment were emitted from a point in the center of the increment. He then computed the relative effect of a source upon all other areas and upon the area containing the source; the latter being done by integrating the effect of a uniformly distributed areal source. To determine the effect on an area not directly on the downwind plume centerline, Pooler linearly interpolated between adjacent wind directions. Using this relative effect grid and the monthly average value of wind speed, wind distribution, stability, and contaminant emission rate, Pooler computed the effect of each source on each area. Ninety-five

percent of the concentrations computed with this model were within a factor of two of the observed monthly concentration.

Turner refined this model by considering each mile square increment as an areal source and by correcting for the effect on an area not directly downwind of the source by the factor

$$f = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

where

f = a correction factor,

y = the horizontal crosswind distance from the plume centerline, and

σ_y = the vertical dispersion coefficient.

The time scale for input parameters and computed concentrations was also reduced to a 2-hour period. Twelve 2-hour concentrations were averaged to give a daily average. Turner reported 58 percent of the calculated concentrations were within ± 1 pphm of observed 24-hour concentrations. Of the 2-hour concentrations, most of the overcalculations occurred near sunrise and sunset, and most of the undercalculations occurred near midday and midnight. Both Pooler's model and Turner's model were applied to Nashville, Tennessee, and were computer-solved.

Clarke's model was a simplified version of Pooler's model and was intended for hand calculation of the concentration of a contaminant at a single receptor. The total area included in the model was divided into irregular areas, each contributing about the same effect to the receptor. The effect of each area on the receptor was assessed at 2-hour intervals by considering the parameters wind speed, wind direction, and atmospheric stability.

Summary

The conclusions reached in the studies of atmospheric dispersion and related phenomena can be summarized as follows:

1. The most functional expression for describing the dispersion of a plume is

$$\chi = \frac{Q}{\pi u y z} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2 - \frac{1}{2}\left(\frac{z}{\sigma_z}\right)^2\right]$$

where

χ = the ground level concentration

Q = the emission rate,

π = the constant 3.141...,

u = the wind speed,

σ_y = the horizontal crosswind dispersion coefficient,

\overline{J}_z = the vertical crosswind dispersion coefficient,

y = the horizontal displacement from the plume centerline, and

z = the effective stack height.

The units on these variables may be in any consistent set. This expression describes the plume as being normally distributed about the centerline axis with the horizontal variance \overline{J}_y^2 and the vertical variance \overline{J}_z^2 .

2. The most comprehensive set of data for defining \overline{J}_y and \overline{J}_z was compiled by Meade and Pasquill (26) and presented by Gifford (27). These data are shown in Figures 1 and 2.
3. In general, dispersion is greater in urban areas because of mechanical and thermal turbulence. The increased rate of dispersion can be accounted for mathematically by increasing the values of the dispersion coefficients. Local dispersive effects cannot be accounted for in a general dispersion equation.
4. The time scale of all time dependent parameters in the dispersion equation must be adjusted to a consistent time base. These corrections can be made with the aid of Figure 3.
5. There is no one plume rise formula that will give entirely satisfactory results. The best formulas appear to be the Holland formula (42) and the Thomas formula (43), the latter being an extension of Holland's formula. The Thomas formula predicts the maximum plume rise. This maximum was reported to occur at a distance of about one

mile from the source. Other studies (47,48) indicated that the plume rise is theoretically unlimited and is proportional to an exponential function of the downwind distance. In practice, however, the plume rise is affected by discontinuities in the vertical stability structure.

CHAPTER II

PURPOSE AND SCOPE

The problem was to develop an atmospheric dispersion model, using computer methodology, for use in an urban area. The proposed model was to compute the ground level concentration of gases dispersed from multiple sources under varying meteorological conditions.

Although the model was to be used immediately in the Jacksonville-Duval County, Florida, area, it was made as general as possible, within the practical limits of computer time and number of input variables, so that it could be used in almost any area of comparable physical size.

The development of the model was based upon formulas and relationships that were in general use and had been fairly well substantiated by field studies.

The variables accounted for in the model were the emission rate of contaminants from distributed and point sources, physical parameters describing the sources, the

wind speed and direction, and the atmospheric stability structure. These factors can be varied hourly on any integral multiple thereof. The output variable is the ground level concentration of the contaminant computed for receptors located at one-mile intervals in the north-south and east-west directions.

A sulfur dioxide emission inventory was compiled for the months of December, 1965, and January, 1966. These emissions, together with meteorological data for these months, collected as part of the Greater Jacksonville Air Pollution Control Program during the period from October, 1964, to January, 1966, were used as input variables to test the model. The results from the model, the ground level sulfur dioxide concentrations, were compared with observed daily and monthly sulfur dioxide concentrations collected as part of the Jacksonville program.

CHAPTER III

THE MODEL

General Description

The purpose of an atmospheric dispersion model is to describe the ground level concentration of an air pollutant with a minimal expenditure of time and effort. Depending upon the requirements of the model, the time over which the concentration is averaged can range from hourly periods to seasonal periods.

Time scale

For flexibility, the model was designed so that the period over which the input and output factors were averaged could be varied over any integral multiple of an hourly period between 1 and 24 hours. The period of time over which the output is averaged, however, does not need to be the same as the period for which the input variables are averaged.

Basically, the input parameters (Table 3) are

TABLE 3

INPUT PARAMETERS FOR THE DISPERSION MODEL

AREA	- the effect of the emissions from a unit areal source upon a receptor at the center of the source. There are 25 factors -- one for each combination of the 5 stability classes and wind speeds of 1,2,3,4, and 5 miles per hour.
CSN	- the cosine function of the 16 wind direction angles.
SN	- the sine function of the 16 wind direction angles.
N	- the number of cards to be read.
R	- the east-west displacement of a point source from the center of areal source I,J. The displacement is in meters with east positive.
S	- the north-south displacement of a point source from the center of areal source I,J. The displacement is in meters with north positive.
ZPHY	- the physical stack height of point source I,J,M in meters.
M	- the source number within area I,J. The areal source is M = 1 and the point sources are M = 2 - 5.
KEY	- the number of sources in area I,J. The range of KEY is 1 - 5.
KODE	- the number of hours over which the output is averaged.

TABLE 3--Continued

KONT	<ul style="list-style-type: none"> - a switch controlling the title on the output. <ul style="list-style-type: none"> = 1 for the contaminant sulfur dioxide = 2 for the contaminant oxides of nitrogen = 3 for the contaminant fluorides = 4 for the contaminant hydrocarbons = 5 for the contaminant oxidants
MTHAVG	<ul style="list-style-type: none"> - a switch controlling whether or not the output is averaged over the total number of days for which data are read.
NUMDAY	<ul style="list-style-type: none"> - the number of days for which data are read into the model.
ITIME	<ul style="list-style-type: none"> - the number of hours over which the input parameters are averaged.
HALIV	<ul style="list-style-type: none"> - the decomposition half life of the contaminant in hours.
KSTAB	<ul style="list-style-type: none"> - the hourly stability classification. <ul style="list-style-type: none"> = 1 for extremely unstable = 2 for moderately unstable = 3 for slightly unstable = 4 for neutral = 5 for slightly stable
TOP	<ul style="list-style-type: none"> - the height to the base of inversions aloft in hundreds of feet. If no inversion is recorded, the limiting value of TOP is given in Table 2.
BTM	<ul style="list-style-type: none"> - the height to the top of inversions based at or near the ground in hundreds of feet. If no such point exists, set BTM = 100.
YR	<ul style="list-style-type: none"> - the year for which the data apply.
AMO	<ul style="list-style-type: none"> - the month for which the data apply.

TABLE 3--Continued

DAY	- the day for which the data apply.
DIRVEL	- twelve 1-hour averages of wind direction, on a 16-point compass, and wind speed, in miles per hour, on each of two cards.
IHRA	- the hour ending IHRA is the hour through which the hourly areal source emissions which follow are constant.
Q(I,J,1)	- the areal source emission rate for area I,J in grams/hour.
IHRP	- the hour ending IHRP is the hour through which the hourly point source emissions which follow are constant.
Q(I,J,NS)	- the point source emission rate for point source I,J,NS (NS = M) in grams/hour.

hourly averages and are read into the computer for a 24-hour period. The ground level concentration at each receptor is computed for hourly periods and is either printed out or stored in the computer to be averaged over a longer period of time. The input parameter KODE determines the period of time in hours over which the output is to be averaged. For example, if the output -- the ground level concentration -- is to be averaged over a 12-hour period, KODE would be read as 12. The range of KODE is 1 to 24.

If the concentration is to be averaged over a period greater than 24 hours, it can be done by setting KODE to 24 and then averaging multiples of 24-hour-period concentrations. Thus, if the concentration is to be averaged for a period of 72 hours, the concentrations from three 24-hour periods would have to be averaged. Averaging for periods of time greater than 24 hours can be accomplished within the model by setting the input parameter MTHAVG equal to 2 and the parameter NUMDAY equal to the number of days for which the average was required.

To average the meteorological input factors over an n hour period, where n is an integer greater than 1, the input parameter ITIME is set equal to n and the averaged factor is read in as an hourly value every n-th hour. For example, if the meteorological factors are to be averaged over a 3-hour period, the average value for the first three hours would be read in at the third hour with the first and second hour being blank. The average of hours 4,5, and 6 would be read in at the sixth hour and so on.

Spatial scale

The storage capacity of the IBM 709 computer limited the area included in the model to a 15- by 15-mile square. This scale was large enough to include all major sources of

emissions in the Jacksonville-Duval County area. The 15-by 15-mile area was subdivided into 1-mile-square increments by a north-south, east-west grid system (Figure 4). The center of each area increment was considered a receptor, i.e., a point for which the pollutant concentration was calculated. The 1-mile dimension was selected primarily because of work by Pooler (58) and Turner (60,61), which indicated that concentrations for receptors at this spacing would satisfactorily describe the pollution pattern and would not result in an excessive number of computations.

Meteorological factors

When the Jacksonville program began, five stations for recording wind direction and speed were established within the area (Figure 4). As the study progressed, analysis of the wind data revealed that the results from stations 1 and 5 and stations 3 and 4 were nearly identical. As a result of this finding, stations 3 and 5 were discontinued midway through the survey (62). The stations retained were located at the U.S. Weather Bureau (station 1) north of the city of Jacksonville at an elevation of 17 feet, at a power generating station (station 4) in the city's major industrial zone east of the St. Johns River at an elevation

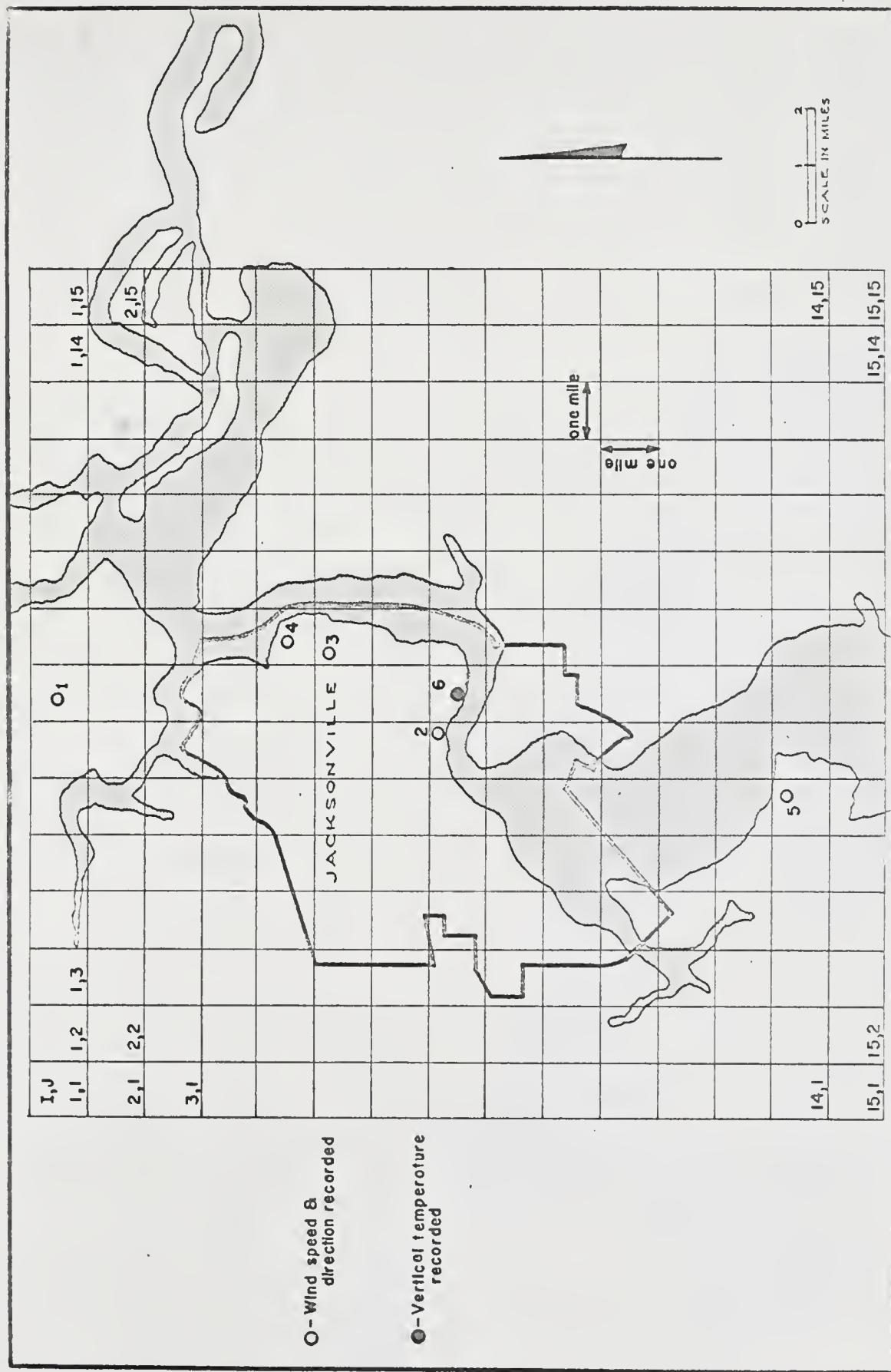


FIGURE 4 - COMPUTATION GRID AND METEOROLOGICAL NETWORK

of 50 feet, and on top of City Hall (station 2) in downtown Jacksonville at an elevation of 250 feet. Both wind speed and direction were recorded continuously at all stations by a Bendix-Friez Aerovane and a strip chart recorder. Hourly averages of wind speed, in miles/hour, and wind direction, from 16 points, were reduced from these charts and put on punch cards. These data were input parameters of the model and in addition were sorted by the computer program listed in Appendix 4 for plotting wind roses.

An inspection of the data revealed that there was no significant difference in the wind speed and direction recorded at station 1 and that recorded at station 4. The wind speed at station 2 was generally higher than the wind speed recorded at the other stations during most periods, but the direction was essentially the same. The higher wind speed could be ascribed to the elevation of station 2. Since there was no significant spatial variation in wind direction, and the wind speed at stations 1 and 4 was about the same, it was decided that the wind data from one station could be used to describe the conditions for the entire area. The wind data from station 4 were selected for this purpose primarily because it was located in the zone of heaviest emissions and because the elevation of the station

was close to the height at which most contaminants were emitted.

The atmospheric stability was determined by direct measurement of the vertical temperature profile. This was considered an improvement over the indirect method suggested by Pasquill (28) and used by Turner (60). The vertical temperature profile was measured to 750 feet with a system using thermistors (63). These were placed at the 100-, 200-, 300-, 450-, and 750-foot levels of a TV tower (station 6, Figure 4) located in a relatively unrestricted area at the center of the grid. The system measured the temperature at ground level and the temperature difference between the ground and each of the five levels. Radio observations made by the U.S. Weather Bureau at 0700 and 1900 hours were relied upon for information about the vertical structure of the atmosphere above 750 feet. Based upon the measurements of the vertical temperature and wind speed, hourly classifications of atmospheric stability were assigned. The criteria used to define the stability classes are presented in Table 4.

In addition to the stability classification the base of inversions aloft and the top of ground level inversions were recorded if either existed. Inversions aloft were of interest because of the limit they impose upon the

TABLE 4

CRITERIA FOR ATMOSPHERIC STABILITY CLASSIFICATION

Wind Speed (mph)	Lapse Rate ($^{\circ}\text{F}/1000 \text{ ft.}$)				
	- 11.0	-11.0 to -9.0	-9.0 to -5.0	-5.0 to +7.0	+7.0
2	1*	2	2	4	4
2 - 4	1 - 2	2	3	4	4 - 5
4 - 6	2	2 - 3	3	3 - 4	4
6	2	3	3	3 - 4	4

- *1 - Extremely unstable.
- 2 - Moderately unstable.
- 3 - Slightly unstable.
- 4 - Neutral.
- 5 - Slightly stable.

vertical mixing depth. The tops of ground level inversions were recorded since it was assumed that gaseous material emitted above this level was prevented by the stable layer from reaching the ground.

Sources

The model was designed to account for both point sources and areal sources. Within each area increment, the model can handle five sources; the first source always being the areal source. The input parameter KEY (I,J)

defines the number of sources in each area increment I,J where I is the northerly coordinate of the area increment (increasing north to south) and J is the easterly coordinate of the area increment (increasing west to east).

The areal sources consisted of emissions from small individual sources within each 1-mile square described by the grid system. The emissions were combined and were assumed to be uniformly distributed over the entire area. The emission height of these sources was assumed to be 8 meters. Exceptions were made when approximately 50 percent or more of an area was water. In such cases the emissions from the area were assumed to be emitted from a point source at the centroid of the land area. The emission height was again assumed to be 8 meters. The emissions from larger sources were considered individually as point sources. A preliminary study with the model indicated that point sources with an emission rate of less than 10,000 grams/hour had a negligible effect on all receptors even under the most adverse meteorological conditions. Therefore only sources with an emission rate greater than 10,000 grams/hour were considered as point sources. The point sources were located within the area increment containing them by an internal coordinate system. The origin was at the center

of the area with north and east considered as positive. The displacement from the origin was measured in meters.

The emissions from areal sources and point sources are read into the computer by separate READ statements. This was done to make the model more flexible and efficient. The areal source emission rates are read in first, preceded by the variable IHRA. IHRA is the hour through which the areal emission rates are valid. If IHRA is read as 8, this would indicate that the areal emission rates following were valid through the hour ending at 0800 hours. The emission rates of all areal sources are read at one time by this READ statement.

The point source emission data are read next, preceded by the variable IHRP. IHRP is the hour through which the point source emission rates are valid. The emission rate of each point source is read individually preceded by the source identification, i.e., the I,J coordinate of the area containing the source and the source number within that area NS. Once an emission rate $Q(I,J,NS)$ is read for a particular point source, the value is held until another value of $Q(I,J,NS)$ or zero is read.

Factors related to the physical definition of

point sources are the northerly displacement S and the easterly displacement R from the center of the area and the physical stack height of the source ZPHY. These factors are read preceded by the same I,J,NS identification that preceded the point source emission data.

The other factors read into the model are defined in Table 3 and in the program listing in Appendix 1.

Mathematical Equations

The basic dispersion equation used in the model was an equation of mass continuity with a crosswind distribution described by the Gaussian interpolation formula. The equation is

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right)\right] \quad [1]$$

where

χ = the ground level concentration in grams/cubic meter,

Q = the point source strength in grams/second,

π = the constant 3.141...,

u = the mean wind speed in meters/second,

y = the horizontal crosswind displacement from the plume centerline in meters,

z = the effective source height in meters,

σ_y = the horizontal crosswind dispersion coefficient in meters, and

σ_z = the vertical crosswind dispersion coefficient in meters.

The right-hand side of Equation 1 contains a multiplicative factor of 2, which is the conventional means of accounting for the assumed plume reflection by the ground. This equation was used to calculate the effect of point sources.

The effect of areal sources was determined by treating the source as a crosswind line source and using a receptor oriented plume (64) in conjunction with the crosswind integrated form of Equation 1. The equation obtained by integrating Equation 1 with respect to y from $+\infty$ to $-\infty$ is

$$\chi_c = \frac{\sqrt{2} Q}{\sqrt{\pi} \sigma_z u} \exp\left(-\frac{z^2}{2\sigma_z^2}\right). \quad [2]$$

The receptor oriented plume concept considers the plumes originating at the receptor and extending upwind. The same relationship exists between sources and receptor as would exist if the plumes were considered to originate at the actual sources and be carried downwind to the actual

receptor. The advantage of this procedure is that all computations pertaining to a receptor can be made at one time.

If the actual source was an infinite line source of strength Q grams/meter-second/foot, its effect could be calculated directly with Equation 2 by using the receptor oriented plume concept. However, since the sources considered in the development of the model were of finite length a correction had to be applied. Mathematically, the correction is the fraction of the area under the normal distribution curve which falls between the end points of the line source, P_1 and P_2 . The value of the factor varies between 0 and 1 and is determined by integrating the area under the normal curve between P_1 and P_2 . The expression for the integration is

$$F = \frac{1}{\sqrt{2\pi}} \left[\int_0^{P_2} \exp\left(-\frac{P_1^2}{2}\right) - \int_0^{P_1} \exp\left(-\frac{P_2^2}{2}\right) \right] \quad [3]$$

where

F = correction factor, and

P_1 and P_2 = the end points of the line source measured from the plume centerline and normalized in terms of \bar{Y}_y .

Each integral can be approximated by the equation

(65)

$$K = \int_0^x \frac{\exp(-\frac{x^2}{2})}{\sqrt{2\pi}} \cong \frac{\exp(-\frac{x^2}{2})}{\sqrt{2\pi}} \left(\frac{x}{1} - \frac{x^2}{3} + \frac{2x^2}{5} - \dots \right). \quad [4]$$

By using five terms of the continuous fraction, Equation 4 reduces to

$$K \cong \frac{\exp(-\frac{x^2}{2})}{2} \cdot \frac{(945+105x+8x^3)x}{945-210x+15x^4}. \quad [5]$$

Equation 5 approximates the normal integral within 94 percent between 0 and 2.15 standard deviations. Beyond 2.15 σ the approximation diverges rapidly from the true value.

The factor of Equation 3 can now be represented as

$$F = K_{P2} - K_{P1}$$

with K_{P1} and K_{P2} being determined by Equation 5 with $x = P1$ and $P2$ respectively.

Distributed sources were considered as crosswind line sources with a length equal to the crosswind dimension of the distributed source, and their effects were determined by combining Equations 2 and 6

$$\chi_c = \frac{\sqrt{2} Q F}{\sqrt{\pi} u \sigma_z} \exp\left(-\frac{z^2}{2\sigma_z^2}\right). \quad [7]$$

The downwind distance was considered as being from the receptor to the center of the distributed source. Figure 5 illustrates this concept.

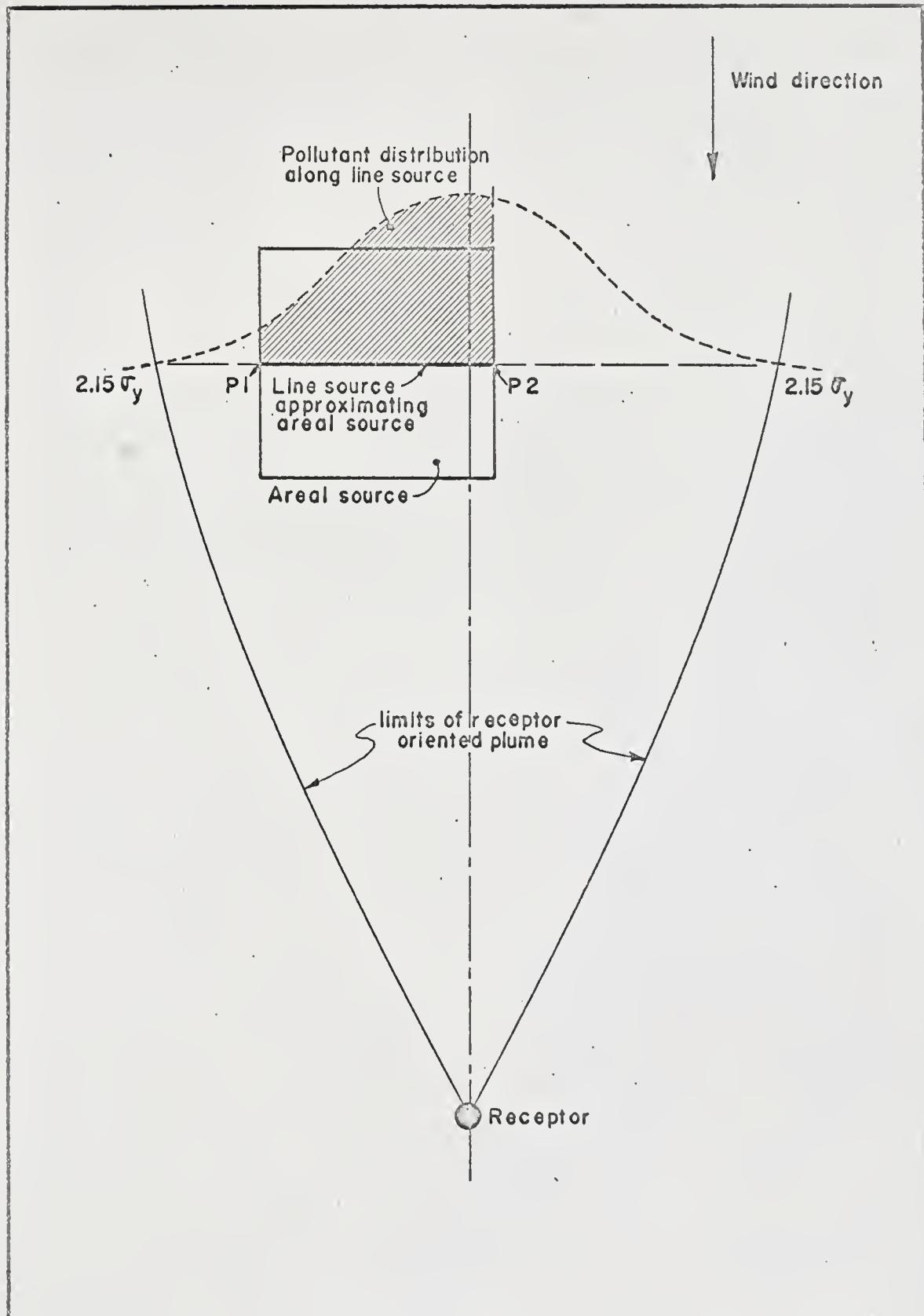


FIGURE 5- TREATMENT OF EXTERNAL AREAL SOURCES

Equations for the dispersion coefficients, σ_y and σ_z , were approximated by fitting equations to the curves presented by Gifford (27) (Figures 1 and 2). The curves for σ_y were approximated by an equation of the form

$$\sigma_y = ax^b \quad [8]$$

and those for σ_z by fitting a quadratic to three logarithmic values selected from the curves. The equations derived are

Stability Class 1 -- Extremely unstable

$$\sigma_y = 0.35x^{0.9} \quad [9a]$$

$$\sigma_z = \exp(10.81 - 4.07\ln x + 0.495\ln^2 x) \quad [10a]$$

Stability Class 2 -- Moderately unstable

$$\sigma_y = 0.22x^{0.9} \quad [9b]$$

$$\sigma_z = \exp(3.82 - 1.25\ln x + 0.200\ln^2 x) \quad [10b]$$

Stability Class 3 -- Slightly unstable

$$\sigma_y = 0.18x^{0.9} \quad [9c]$$

$$\sigma_z = \exp(-2.28 + 1.00\ln x - 0.011\ln^2 x) \quad [10c]$$

Stability Class 4 -- Neutral

$$\sigma_y = 0.13x^{0.9} \quad [9d]$$

$$\sigma_z = \exp(-3.27 + 1.23\ln x - 0.038\ln^2 x) \quad [10d]$$

Stability Class 5 -- Slightly stable

$$\bar{C}_y = 0.10x^{0.9} \quad [9e]$$

$$\bar{C}_z = \exp(-387 + 1.28\ln x - 0.0521^2 x) \quad [10e]$$

where

x = the distance from the source to the receptor in meters.

Gifford's stability class F -- moderately stable -- was not considered because of the mechanical and thermal turbulence induced by an urban area.

The plume rise equation for describing the elevation of a plume from a point source is

$$\Delta H = \frac{(0.147 Vd + 0.41 \times 10^{-4} Q_H)}{u} \left(\frac{x}{2000} \right)^{2/3} (F) \quad [11a]$$

where

ΔH = the plume rise in meters,

V = the stack exit velocity in meters/second,

d = the stack diameter in meters,

Q_H = the heat efflux in calories/second,

u = the wind speed in meters/second,

x = the downwind distance in meters, and

F = a factor to account for the stability class.

The value of F ranges from 1.25 for an unstable lapse

condition to 0.90 for a stable atmosphere. The equation is basically that of Thomas (43). The maximum plume rise, reported to occur at about one mile, was assumed to occur at 2000 meters and was corrected for other distances by the term (48)

$$\left(\frac{x}{2000}\right)^{2/3}. \quad [11b]$$

This resulted in a plume rise greater than that predicted by Thomas for distances beyond 2000 meters. Equation 11a was evaluated with values for the parameters which were assumed to be typical of a large source. The value of Q_H was determined by the relationship

$$Q_H = Q_M C_p \Delta T \quad [11c]$$

where

Q_H = the heat emission rate in calories/hour,

Q_M = the mass emission rate in pounds/hour,

ΔT = the difference between stack temperature and ambient

C_p = the coefficient of specific heat at constant pressure.

The value of C_p for the stack gas was assumed to be equal to C_p for air, i.e., 0.246 calories/gram.

By assuming

$$d = 10 \text{ feet}$$

$$v_s = 2000 \text{ feet/minute}$$

$$\Delta T = 175^\circ\text{C}$$

Equation 11a reduced to

$$\Delta H = 2.4F \left(\frac{x^{0.67}}{u} \right) \quad [11d]$$

For simplicity 11d was used in the model to describe the plume rise from point sources.

The equation for describing the plume rise from dwellings is (50)

$$\Delta H = \frac{2}{u^{0.33}} \quad [12]$$

where

H = the plume rise in meters, and

u = the wind speed in miles/hour.

To account for decomposition of a contaminant in the plume, the exponential decay function was used. This function is

$$DK = \exp \left(-\frac{0.693t}{T} \right) \quad [13]$$

where

DK = the fraction of the original material remaining after a time period t ,

t = the time after emission and can be related to the downwind distance by

$$t = x/u$$

where

x = the downwind distance, and
 u = the wind speed, and

T = the decomposition half life of the contaminant.

Programming Logic

The ground level concentration computed for each of the receptors was considered to be the result of four effects:

1. The effect of emissions from an areal source upon a receptor located at the center of the area, henceforth referred to as the effect of an areal source.
2. The effect of emissions from a point source upon a receptor located in the same grid area as the source; the effect of an internal point source.
3. The effect upon a receptor of emissions from areal and point sources located outside of the area containing the receptor, the effect of external areal and point sources.
4. The effect of the airborne material one time period after the period of emission; the effect of a drifting plume.

These effects are assessed by the model, which is written in FORTRAN II language compatible with the IBM 709 computer.

The cumulative effect can be either printed out or stored for future use in the computer.

Effect of an areal source

The emissions from an areal source were defined as the combined emissions from all small sources within the area. These emissions were assumed to be uniformly distributed over the entire area.

With the receptor at the center of the area, only the material emitted in the upwind half of the area has a chance of reaching the receptor. Regardless of the wind direction, half of the emissions will occur upwind; only the distribution will change. With the crosswind limits of the plume considered to be $\pm 2.15\sigma_y$, the difference in distribution is noticeable only near the upwind edge of the area. Because of the relatively great distance to this point the difference was assumed to be insignificant, thus making the effect of an areal source independent of wind direction. The effect is dependent upon wind speed, however, both because of the diluting effect of the wind and because of the effect of wind speed on plume rise. The latter effect is noticeable only for wind speeds of 4 miles/hour or less. Above 4 miles/hour there is essentially no

plume rise (50) and the ground level concentration is proportional only to the inverse of the wind speed.

The relative areal source effect was determined for each combination of the five stability classes and wind speeds of 1, 2, 3, 4, and 5 miles/hour. This was done by numerically integrating the effect of the upwind emissions in eight 100-meter increments by using Equation 2. The twenty-five factors so determined are the effect of a unit areal source emission rate for the given meteorological conditions and have the units (grams/cubic meter)/(grams/hour) or χ/Q . The relative effect factors are constant for the conditions calculated and are part of the input data of the program. The factors are presented in Table 5.

For wind speeds greater than 5 miles/hour, the 5-mile/hour factors are reduced in proportion to the inverse of the wind speed, by the expression

$$A_i^s = A_5^s \left(\frac{5}{u_i} \right)$$

where

A_i^s = the relative effect factor for a wind speed of u_i miles/hour and a stability class s , and

A_5^s = the relative effect factor for a wind speed of 5 miles/hour and the same stability class.

TABLE 5

THE GROUND LEVEL CONCENTRATION AT THE CENTER OF AN AREAL SOURCE
IN MICROGRAMS/CUBIC METER FOR A UNIT EMISSION* RATE
FROM THE SOURCE

Atmospheric Stability Class	Wind Speed (mph)				
	1	2	3	4	5
1	16 x 10 ⁻¹⁰	21 x 10 ⁻¹⁰	19 x 10 ⁻¹⁰	6 x 10 ⁻¹⁰	1 x 10 ⁻¹⁰
2	9	13	13	8	2
3	7	10	11	9	5
4	6	8	10	11	9
5	5	7	9	11	10

*A unit emission rate is defined as the emission at the rate of 1 gram/
hour.

For a wind speed of 0 miles/hour, a calm, the vertical dispersion coefficient was assumed to increase at a rate equivalent to the rate of increase for a wind speed of 1000 meters/hour. The emissions from all sources, both areal and point sources, were assumed uniformly distributed over the entire area with an effective height of $2.15\sigma_z$ unless limited by meteorological conditions. The resulting expression for determining the relative ground level concentration for periods of calm is

$$\frac{X}{Q} = \frac{\sqrt{2}}{\sqrt{\pi} (1609)^2 z} \exp\left(-\frac{z^2}{2\sigma_z^2}\right)$$

where

$\frac{X}{Q}$ = the relative ground level concentration in (grams/cubic meter)/(grams/hour),

z = the plume height in meters and is equal to $2.15\sigma_z$ unless limited by meteorological conditions,

σ_z = the vertical dispersion coefficient in meters, and

1609 = the number of meters/mile.

The ground level concentration at each receptor from the areal sources is computed by multiplying the relative effect factor by the emission rate from the source.

This effect is assessed by subroutine CREA, which

is called near statement number 21 in the main program.

Subroutine CREA is listed in Appendix 1.

Effect of an internal point source

The ground level concentration contributed to a receptor by an internal point source is determined by Equation 1. To determine the downwind and the crosswind distances for the equation, the north-south east-west coordinate system which located the point source with respect to the receptor is rotated so that the east-west, or the R, axis becomes parallel to the wind direction. The rotation is accomplished by first rotating the axes through an integral multiple of 90 degrees so that the wind direction appears to be in the northerly quadrant. This quadrant includes the directions NNW, N, NNE, and NE. The axes are then rotated so that the translated R axis corresponds to the wind direction with the upwind direction being positive. The translated values of R and S correspond to the downwind distance x and the crosswind distance y, respectively.

The physical stack height ZPHY of the source is compared with BTM. BTM is a meteorological factor and is the height to the top of an inversion based at or near the ground. It was assumed that when ZPHY was equal to or

greater than 0.8 BTM, the plume rise would carry the plume up into the turbulent zone above the inversion, and that the stable air near the ground would prevent any of the emitted gaseous material from reaching the ground. Thus, the effect on the ground level concentration would be zero. When ZPHY is less than 0.8 BTM, the effective stack height z is determined by adding the plume rise as determined by Equation 11a to the physical stack height of the source. The computed effective stack height is then compared with the meteorological factor TOP, which is the height to the base of an inversion aloft -- the limit of vertical mixing. If z exceeds TOP, it is set equal to TOP, implying that the plume will rise only to the base of the inversion.

The value of \bar{J}_y and \bar{J}_z is calculated by Equation 9 and 10 respectively. \bar{J}_z is compared with 0.67 TOP and if it is greater it is set equal to 0.67 TOP. This limits the vertical spread of the plume when an inversion exists aloft.

Decomposition of the contaminant is accounted for by Equation 13 with the contaminant half life read hourly. The half life was made to vary hourly primarily to account for the effects of changes in humidity and intensity of sunlight on the half life of sulfur dioxide (66).

The ground level concentration from internal point sources is computed by subroutine PTIN, which is called near statement 76 in the main program. Subroutine PTIN is listed in Appendix 1.

Effect of external areal and point sources

These sources were considered together only because the computation of the source-receptor distance for both sources involves many of the same steps. Considering them together eliminated a replication of computations. Other than this the treatment of the source effects differs completely and will be discussed separately.

Effect of external areal sources.--This effect is assessed similarly to the effect of an areal source, the main exception being that this effect is dependent upon wind direction.

A relative effect grid is computed which expresses the relative effect of an external areal source on all receptors except the one within the source. This is done by determining the downwind and crosswind distance from the source to each receptor by the procedure described on page 51 and by using Equation 7 to compute the relative effect.

It was assumed that if the crosswind distance to the center of the source exceeded $2.15 \bar{U}_y$, the effect on that receptor was negligible. Also, if the downwind distance from source to receptor was greater than the distance that the wind could have carried the emitted material, no effect was noted at the receptor.

In the vertical direction, the value of \bar{U}_z was assumed limited to 0.67 TOP for reasons previously discussed. The plume rise is computed by Equation 12 and is assumed not to be affected by TOP or BTM, since the rise is always relatively small.

In computing the factor for Equation 7 that corrects for a finite length line source, the length of the line source was assumed to be 1609 meters long regardless of the wind direction. Also, the entire areal source was represented by one line source rather than by numerically integrating the source effect as was done when determining the effect of an areal source. A comparison of the effect as determined by this method and the effect as determined by considering the source in three increments showed a discrepancy of only 4 percent for a source-receptor distance of one mile. At greater distances the difference would become smaller. Therefore it was considered justifiable

to approximate the source by only one line source.

Since the plume, in this case, can travel quite a distance before reaching the receptor, the decomposition of the contaminant is accounted for by Equation 13. This is the equation of the exponential decay function.

The effect of all areal sources upon each receptor is determined by locating the relative effect grid at each source and multiplying that source strength by the relative effect on each receptor. The resultant effect at each receptor is the cumulative effect from all areal sources.

Effect of external point sources.--The downwind distance from a point source in area I,J to a receptor is equal to the downwind distance of areal source I,J to the receptor plus the downwind distance from the point source to the center of area I,J as determined in the effect of an internal point source. The crosswind distance from the point source to the receptor is equal to the sum of the corresponding crosswind distances.

If the crosswind distance is greater than $2.15 \sqrt{y}$, the effect on the receptor is considered negligible. No effect is computed where the downwind distance exceeds the distance the plume could have been carried by the wind.

The effect of an external point source is computed by Equation 1 with a correction added to account for decomposition of the contaminant.

The effect of external areal and point sources is assessed in subroutine OARPT, listed in Appendix 1. Subroutine OARPT is called at statement 76 in the main program.

Effect of a drifting plume

The effect of an airborne material, one period after emission, was considered with respect to the wind conditions of the current and preceding time periods.

Drifting plume with a change in wind direction.--

The plume, as it appeared at the end of the preceding time period, was assumed to be a line coinciding with the plume center line with a concentration distribution described by crosswind integrated concentrations at the ground level. The line was assumed to be carried in the new direction of the wind and to affect the receptors it was blown over (Figure 6).

The effect at a receptor is determined by computing the crosswind integrated concentration of the plume at the point on the original plume centerline which passed over the receptor. This concentration is reduced to account for contaminant decomposition (Equation 13) and vertical dis-

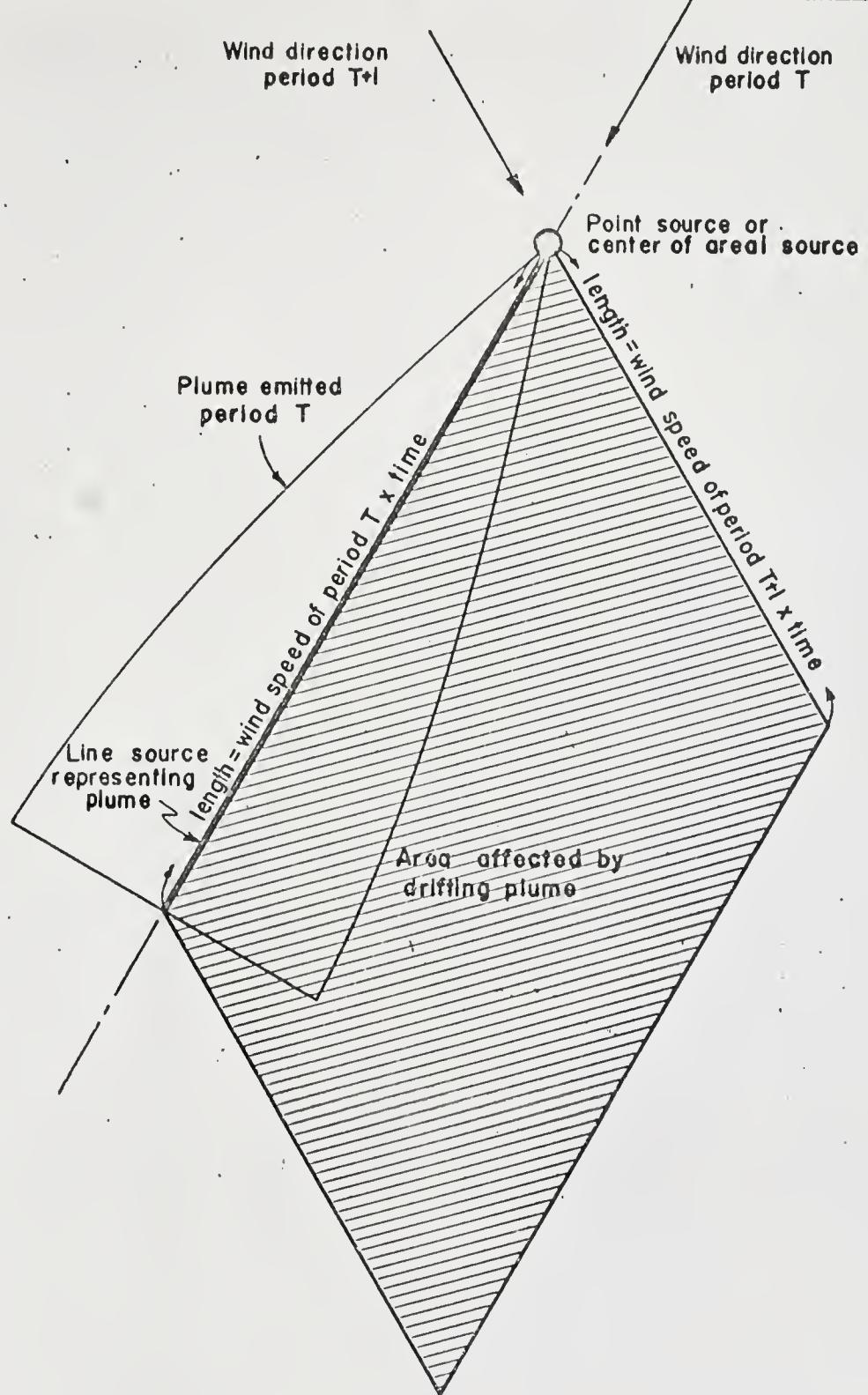


FIGURE 6- AREA AFFECTED BY DRIFTING PLUME WHEN WIND DIRECTION CHANGES

persion; the latter being accounted for by the relationship

$$\chi \propto \frac{(\tau_z)_c}{(\tau_z)_R} C$$

where

χ = the ground level concentration at the receptor,

$(\tau_z)_c$ = the vertical dispersion coefficient on the downwind axis of the original plume, and

$(\tau_z)_R$ = the vertical dispersion coefficient determined for travel distance in the current and preceding wind direction.

The area affected by the drifting plume is described by a parallelogram with one corner at the source and two sides parallel to and in the direction of the wind of the previous time period and equal in length to the product of that wind speed and the time period. The other two sides are parallel to and in the direction of the wind of the current time period and equal in length to the product of that wind speed and the time period.

Drifting plume with a calm during the current time period.--When a calm persisted during the time period of computation or if the wind speed and direction were such that the plume did not drift over a receptor, the drifting

plume effect was assumed to be the ground level concentration of the previous hour decreased by decomposition (Equation 13) and turbulent dispersion. The dispersion factor for turbulent dispersion was assumed to be a constant for each stability class and was calculated by the empirical expression

$$E = \frac{(\sigma_y \cdot \sigma_z)_{3000}}{(\sigma_y \cdot \sigma_z)_{4000}}$$

where

E = a reduction factor,

$(\sigma_y \cdot \sigma_z)_{3000}$ = the product of the dispersion coefficients for an equivalent distance of 3000 meters, and

$(\sigma_y \cdot \sigma_z)_{4000}$ = the product of the dispersion coefficients for an equivalent distance of 4000 meters.

This expression was empirically selected because it gave results that agreed with observed data.

The factor E for each stability class is presented in Table 6.

TABLE 6

FACTORS FOR THE DISPERSION OF GROUND LEVEL
MATERIAL DURING PERIODS OF CALM

Stability Class	Dispersion Factor, E
1	0.25
2	0.43
3	0.62
4	0.66
5	0.67

Drifting plume with a calm during the previous time period.--In this situation, the ground level concentration of the previous period was assumed to be the "source." This is reduced at downwind receptors by the factor

$$F = \frac{(\bar{V}_z)_{1000}}{(\bar{V}_z)_x + 1000} \cdot DK$$

where

F = a reduction factor,

$(\bar{V}_z)_{1000}$ = the vertical dispersion coefficient at an equivalent distance of 1000 meters,

$(\bar{V}_z)_x + 1000$ = the vertical dispersion coefficient at a downwind distance $x+1000$ meters from the receptor, and

DK = the exponential decomposition function with the decomposition time taken as the interval between the time of emission and the time of arrival at the receptor.

Horizontal dispersion was not considered explicitly but was accounted for by assuming that as much material diffused into an incremental volume from each side as diffused out -- an equilibrium condition. This assumption would not be valid if a large concentration gradient existed between "sources" or for receptors at the edges of the grid system parallel to the wind direction. Since the occurrence of large concentration gradients is relatively infrequent and the effect near the edge of the grid is small to begin with, the error introduced by this assumption was ignored.

Drifting plume with no change in wind direction.--

The effect of a drifting plume, when there is no change in wind direction, is determined by exactly the same methods as are used to determine the effects of external areal and point sources. The receptors affected are those within the downwind range to which the plume would have been carried during the second time period. This range was defined as

$$u(KT) \cdot ITIME \leq x \leq u(IT) \cdot ITIME$$

where

$u(KT)$ = the wind speed of the previous hour,

$u(IT)$ = the wind speed of the current hour,

ITIME = the length of the time period, and

X = the downwind distance.

Output of the model

The output parameter of the model is the ground level concentration of a gaseous pollutant computed for each element of the 15- by 15-mile grid. The concentrations are printed in terms of both micro-grams per cubic meter and parts per hundred million. The former is printed in the format listed in Appendix 3. The contaminant printed in this title is controlled by the variable KONT. The value of KONT corresponding to a particular contaminant is presented in Table 3.

The concentration in parts per hundred million is printed in square 15 by 15 array with the scale 1/2 inch equal 1 mile. This can be used for plotting concentration isopleths.

The control of the time scale of the output is described in the section entitled Time scale. The time scale of the output is corrected to a time base consistent with the other factors in the model at statement 521 in the

main program. The base time period is one hour and corrections to other output time periods are made with the expression (41)

$$\chi \propto (T)^{-0.14}$$

where

χ = the ground level concentration averaged over some time period T hours.

CHAPTER IV

EMISSION INVENTORY

A sulfur dioxide emission inventory was compiled for the months of December, 1965, and January, 1966. This inventory and the meteorological data for this period were used to test the dispersion model.

The emissions were considered in two categories -- those from dwellings and small sources and those from large individual sources. The emission rate from the latter sources was generally greater than 10,000 grams SO_2 /hour, although this criterion was not strictly adhered to.

Emissions from Industrial, Commercial, and Institutional Sources

A list of the major industries and commercial establishments was compiled from a list of business firms published by the Jacksonville, Florida, Chamber of Commerce. A questionnaire was sent to each firm which was considered a possible source of pollution and also to large institutions

in the area requesting information pertaining to activities on the premises that might result in the emission of air-borne contaminants (63). This included the type, quantity, and sulfur content of fuels and any specific activity that would result in the emission of sulfur dioxide. When additional information was necessary from a particular source, a telephone survey followed the questionnaire.

Several of the major sources were sampled as part of the over-all air pollution study (63). In such cases the sampling and survey data were used to reinforce each other.

As a result of this phase of the emission inventory it was found that the only significant source of sulfur dioxide in Duval County was from the combustion of fuel oils containing various amounts of sulfur. The major portion of the process heat required by industry and commercial firms was produced by the combustion of No. 5 and No. 6 fuel oil. The remainder was from natural gas and No. 2 fuel oil. About half of the commercial space heating requirements were satisfied by oil-fired heaters and half by natural gas.

A preliminary study with the model, using simulated data, revealed that point sources with an emission rate of less than 10,000 grams SO_2 /hour would not greatly affect any

receptor even under the most unfavorable circumstances.

Thus, only sources with emission rates of 10,000 grams/hour or greater were considered individually as point sources. Sources with an emission rate less than this were considered to contribute to the areal source emissions.

There were eighteen sources in the area encompassed by the model that were classified as point sources. These included power generating stations, various industrial and commercial sources, and institutions. In addition to these sources, twenty-seven areal sources were treated as point sources because more than 50 percent of the land area was water. The point sources representing these areal sources were located at the centroid of the land area they represented. The emission rate from these sources is discussed in the next section.

For several of the large users of fuel oil the daily fuel oil consumption was obtained. From these data the average hourly emission rate of sulfur dioxide was determined. For the electric power generating stations it was possible to estimate hourly oil consumption based upon projected hourly power demands for winter months. The hourly power demand as a percentage of the daily demand for a typical winter day is shown in Table 7.

TABLE 7

HOURLY ELECTRIC POWER DEMAND AS A PERCENTAGE OF
 THE DAILY DEMAND FOR THE WINTER SEASON
 IN JACKSONVILLE, FLORIDA

Hour	Percentage of Daily Demand		
	Week Day	Saturday	Sunday
1	3.1	3.4	3.1
2	2.7	3.0	2.9
3	2.2	2.7	2.8
4	2.7	2.9	3.1
5	3.2	3.1	3.4
6	3.8	3.4	3.7
7	4.2	3.6	4.0
8	4.6	3.9	4.3
9	4.7	4.5	4.6
10	4.8	5.0	4.7
11	4.9	4.9	4.7
12	4.7	4.8	4.8
13	4.6	4.6	4.9
14	4.5	4.5	4.6
15	4.4	4.3	4.3
16	4.6	4.6	4.0
17	4.8	4.9	4.4
18	5.1	5.1	4.8
19	5.3	5.3	5.2
20	5.0	5.0	5.0
21	4.6	4.6	4.8
22	4.2	4.3	4.6
23	3.8	4.0	4.0
24	3.5	3.6	3.4
TOTAL	100.0	100.0	100.0

The sulfur dioxide emissions were determined by assuming that 98 percent of the sulfur in the fuel oil was converted to sulfur dioxide during combustion (67). This results in the conversion factor 157 lbs. SO_2 /1000 gallons fuel oil for an oil with a 1 percent sulfur content. Thus the combustion of 2000 gallons of fuel oil with a 3 percent sulfur content would result in the emission

$$Q = 157 \times \frac{2000}{1000} \times 3 = 940 \text{ lbs. } \text{SO}_2.$$

The emission rate from point sources ranged from about 10,000 to over 3,000,000 grams SO_2 /hour. The emission schedule of each point source was assumed to coincide with the work schedule at that place unless more accurate information was available.

Emissions from Dwellings and Small Sources

In Duval County 80 percent of the dwellings are heated by oil heat (68); either No. 2 fuel oil or kerosene. The sulfur content of these fuels averaged about 0.11 percent sulfur by weight (69). The consumption of these fuels and hence the sulfur dioxide emission was based upon the degree-day concept using 65°F as the base. It has been

suggested that the oil consumption for a five-room dwelling is 0.18 gallon/household/degree day (67). This figure was checked using the actual fuel oil consumption for Duval County for December, 1965, and January, 1966 (69), and the corresponding climatological data. The unit consumptions were found to be 0.21 gallon/household/degree day for December and 0.17 gallon/household/degree day for January. The latter values were used when computing the emission rates for the two months.

The quantity of fuel oil and the sulfur content of the oil consumed by small commercial establishments were determined by the survey described in the preceding section. The sulfur dioxide emission rates for these sources was determined by the same procedure as was used for the large sources.

The sulfur dioxide emissions from 80 percent of the dwellings and all small commercial sources within each area increment (Figure 4) were combined and were assumed to be uniformly distributed over the area. Only 80 percent of the dwellings were used, since that was the fraction heating with oil. The expression used to compute the areal source emission rates is

$$Q = [r(\frac{n}{5.0}) N D] (0.157 p) + q$$

where

Q = the SO_2 emission rate in pounds/8 hrs.,

r = the oil consumption factor for dwellings
in gallons/5-room dwelling/degree day,

n = the average number of rooms per dwelling
in each area increment (70),

N = the number of dwellings in each area
increment (70),

D = the number of degree days/8-hr. period,

p = the sulfur content of the fuel oil as
percentage by weight, and

q = the SO_2 emission rate from small sources
excluding dwellings within each area
increment in pounds/8 hrs.

The hourly emission rate for each areal source was computed for three 8-hour periods during the day in order to account for the diurnal temperature pattern. The periods were 0-0800 hours, 0900-1600 hours, and 1700-2400 hours. The emission rates ranged from 0 to about 12,000 grams SO_2 /hour and were assumed constant throughout each period.

Emission Data

The emission rates for the areal sources and point sources were expressed in the units grams SO_2/hour and were read into the program near statement 1006 and statement 1011 respectively.

The emissions from the areal sources and two of the major point sources were computed and punched on cards by the computer program listed in Appendix 2.

CHAPTER V

RESULTS AND DISCUSSION

Sampling Network

The sulfur dioxide sampling network established as part of the Greater Jacksonville Air Pollution Control Program and used for testing the model included 44 lead dioxide candle stations, 11 stations employing the West-Gaeke sampling method, and 2 stations equipped with electroconductivity sampling instruments. The lead dioxide candles were analyzed monthly with the results reported as the sulfation rate in micro-grams SO_3 /square centimeter/day. The West-Gaeke samplers were operated for 24-hour periods three times a week. The results of these samples were expressed as parts per million (ppm) sulfur dioxide. The electroconductivity instruments recorded every five minutes on a continuous schedule. These results were also expressed as ppm sulfur dioxide. Figure 7 shows the location of the sampling stations.



FIGURE 7—SULFUR DIOXIDE SAMPLING NETWORK FOR JACKSONVILLE

Comparison of Observed and Computed
Sulfur Dioxide Concentrations

The sulfur dioxide concentrations observed by the West-Gaeke method were used to test the 24-hour average computed concentrations. The concentrations given by the electroconductivity method were not used for testing the model because there was a discrepancy between these values and those determined by the West-Gaeke method.

A recent study (71) showed the reproducibility of the West-Gaeke method to be ± 0.006 ppm at the 50 percent confidence interval and ± 0.018 ppm at the 95 percent confidence interval in the concentration range 0.01 - 0.25 ppm. As a result of this study the observed and computed concentrations were compared after rounding to the nearest half part per hundred million (pphm) and to the nearest whole part pphm. The comparison was made to the nearest half pphm because the range of observed concentrations was only 0 - 3 pphm.

The sulfur dioxide concentration was observed at the 11 stations for one day in December, 1965, and 11 days in January, 1966. The observed concentrations and the corresponding computed concentrations are presented in Table 8 and Figures 8-19. The computer listing of these data is

TABLE 8
OBSERVED AND COMPUTED SULFUR DIOXIDE CONCENTRATIONS (pphm)

Station	Location	12/26/65	1/4/66	1/6/66	1/9/66	1/11/66	1/13/66	1/16/66	1/18/66	1/20/66	1/25/66	1/27/66	1/30/66
Area	I,J	C*	O*	C	O	C	O	C	O	C	O	C	O
E1	8,10	0.5	0.2	0.3	0.0	0.4	0.0	0.9	1.6	0.2	0.3	0.2	2.4
E2	5,11	0.4	0.0	0.7	0.0	0.4	0.7	0.5	1.1	0.5	0.2	0.1	0.5
E3	11,8	1.2	1.5	0.6	0.3	0.0	0.0	1.0	1.6	0.8	0.9	0.1	0.2
E4	8,13	0.3	0.0	0.1	0.0	0.6	0.0	0.1	M	0.0	0.2	0.2	M
W6	6,6	0.2	0.0	0.4	0.3	0.0	0.0	0.4	0.3	0.2	M	0.9	0.6
W7	8,6	0.2	0.4	0.2	0.5	0.1	0.0	1.2	M	0.1	1.2	0.2	1.4
W8	2,8	0.0	0.0	0.1	0.2	0.9	0.0	0.0	0.1	0.0	0.2	1.3	0.2
W9	8,3	0.1	0.3	0.0	0.0	0.0	0.0	0.2	0.4	0.1	M	0.1	0.5
W11	6,9	2.2	1.6	1.6	3.1	0.1	0.1	1.8	2.0	2.3	0.4	0.4	4.5
W12	7,7	0.6	1.6	1.1	0.9	0.0	0.0	3.1	2.2	1.1	1.6	0.8	1.3
W14	5,8	0.5	0.5	0.8	0.2	0.4	0.1	0.9	0.7	0.6	0.8	1.7	2.1

*C - computed SO_2 concentration (pphm).
O - observed SO_2 concentration (pphm).

[†]M - data missing.

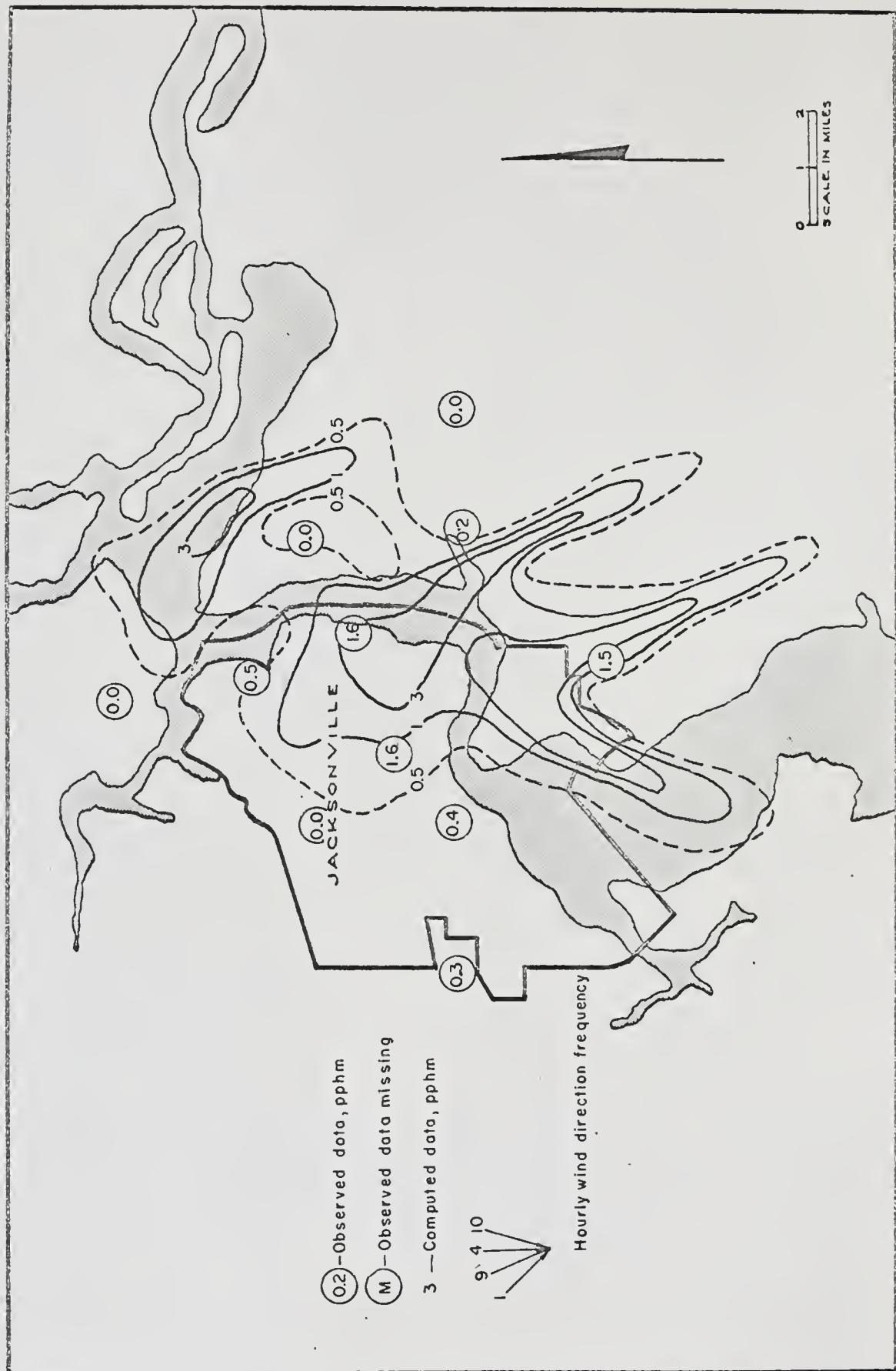


FIGURE 8—OBSERVED AND COMPUTED SO_2 CONCENTRATIONS FOR DEC. 26, 1966

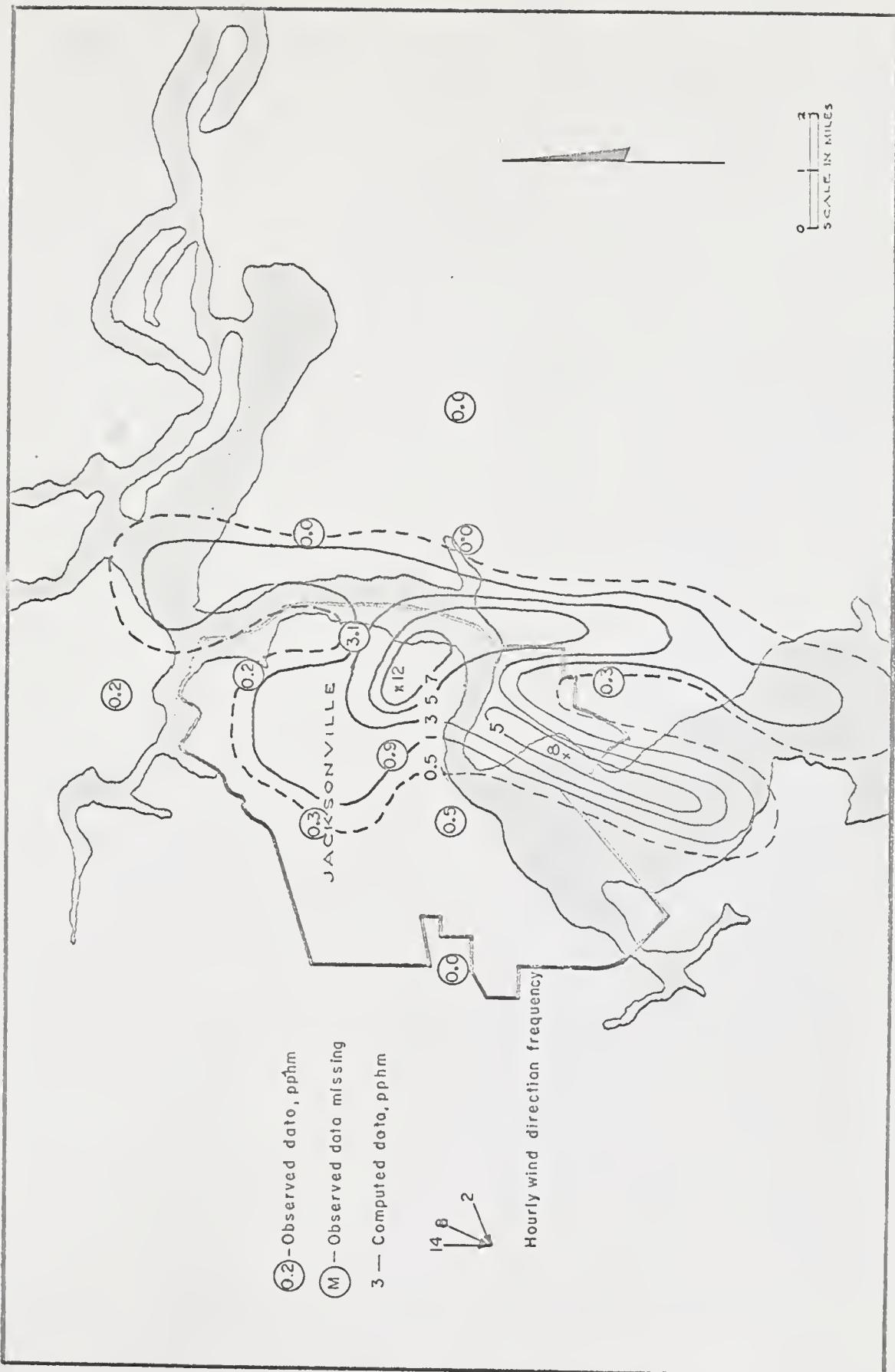
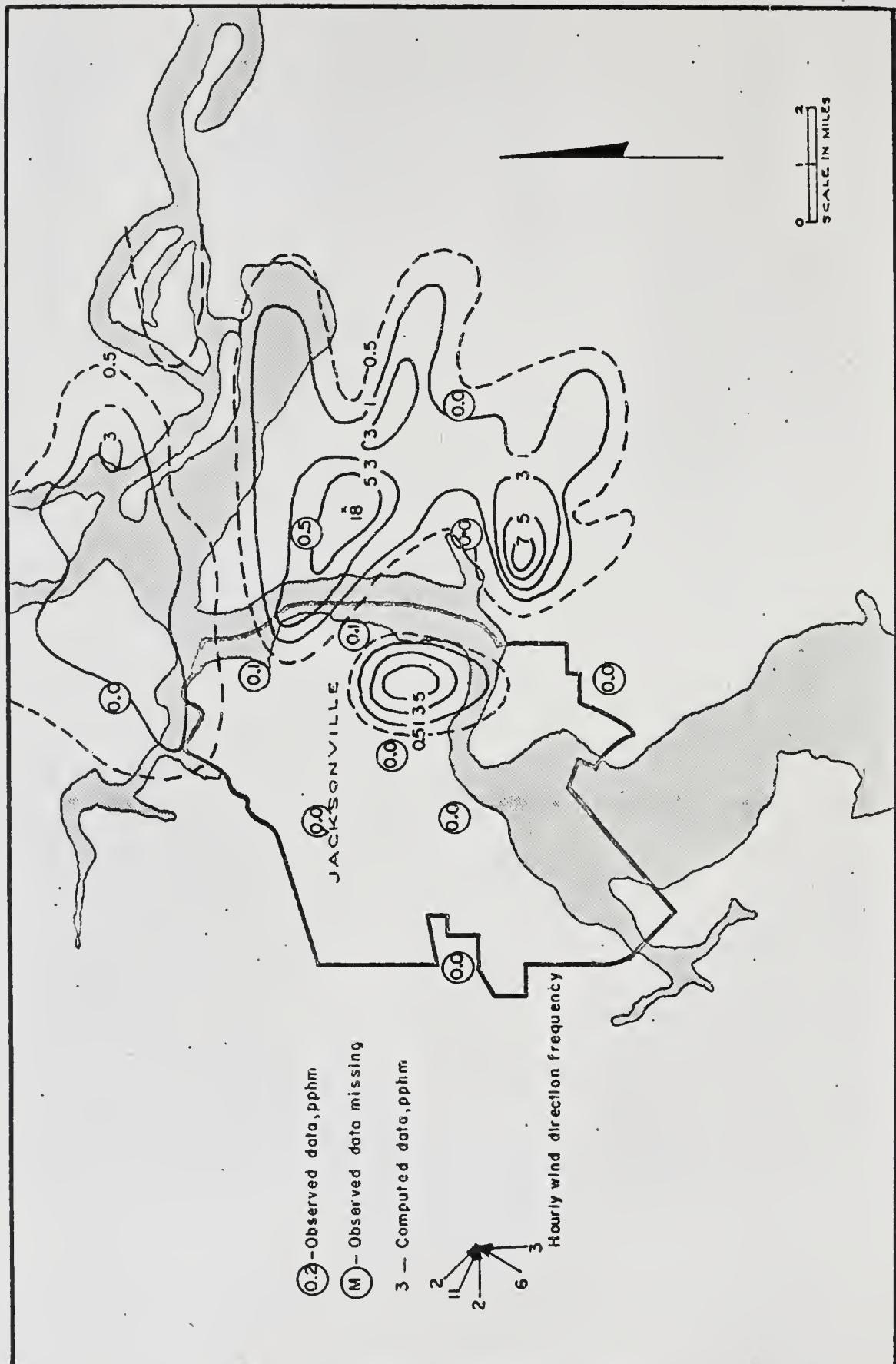


FIGURE 9—OBSERVED AND COMPUTED SO₂ CONCENTRATIONS FOR JAN. 4, 1966



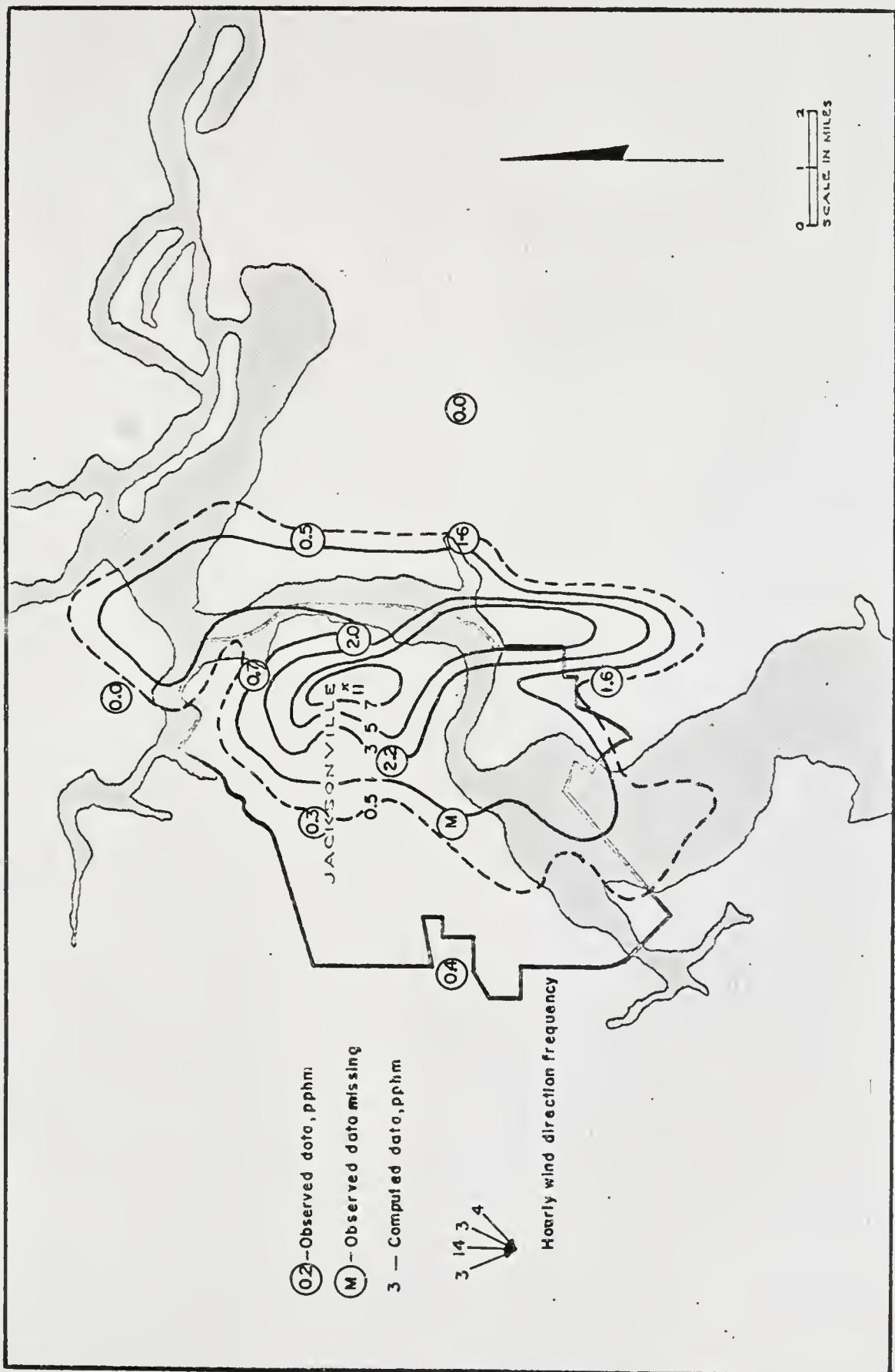


FIGURE II—OBSERVED AND COMPUTED SO_2 CONCENTRATIONS FOR JAN. 9, 1966

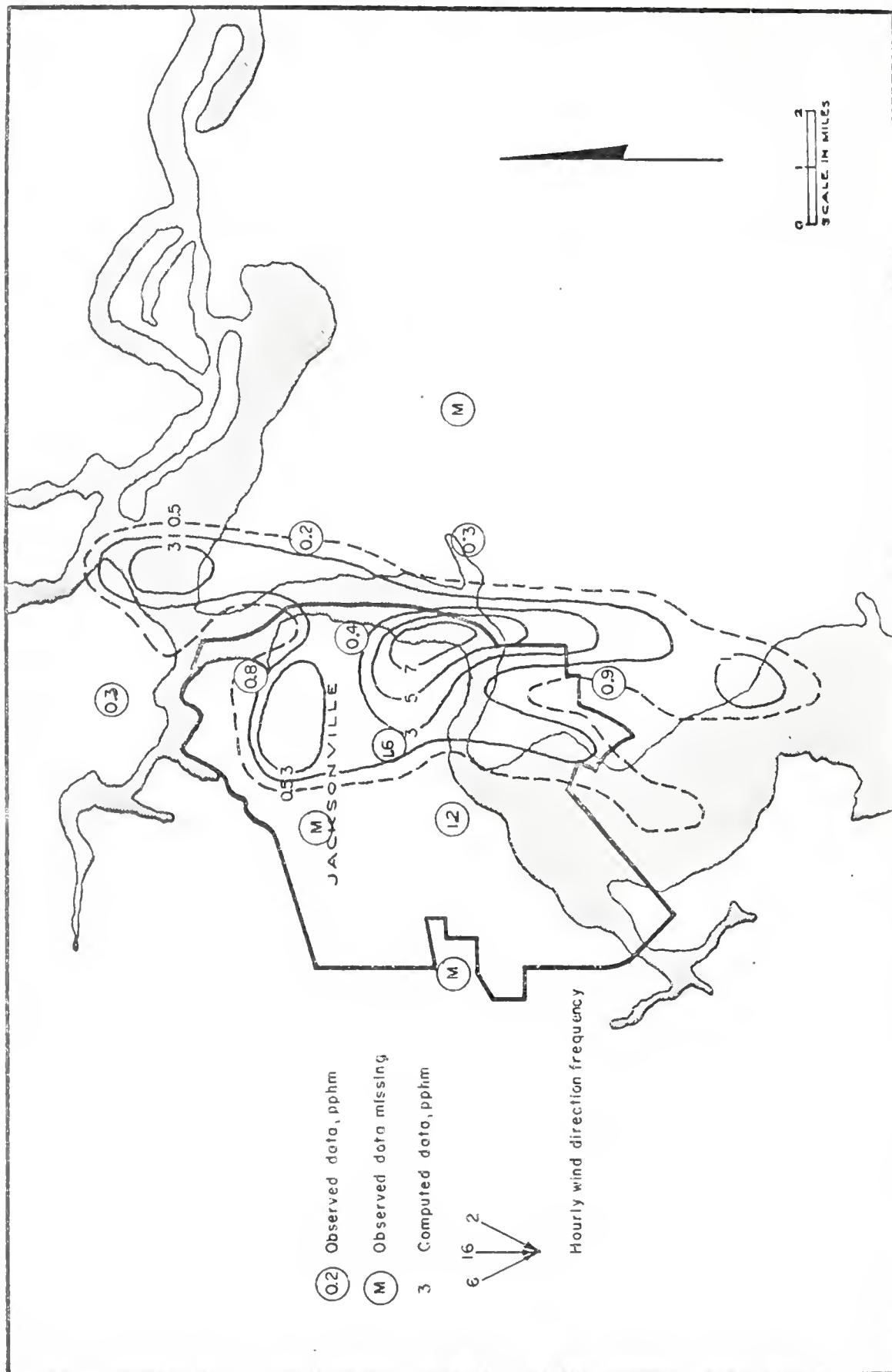


FIGURE 12—OBSERVED AND COMPUTED SO_2 CONCENTRATIONS FOR JAN. 11, 1966

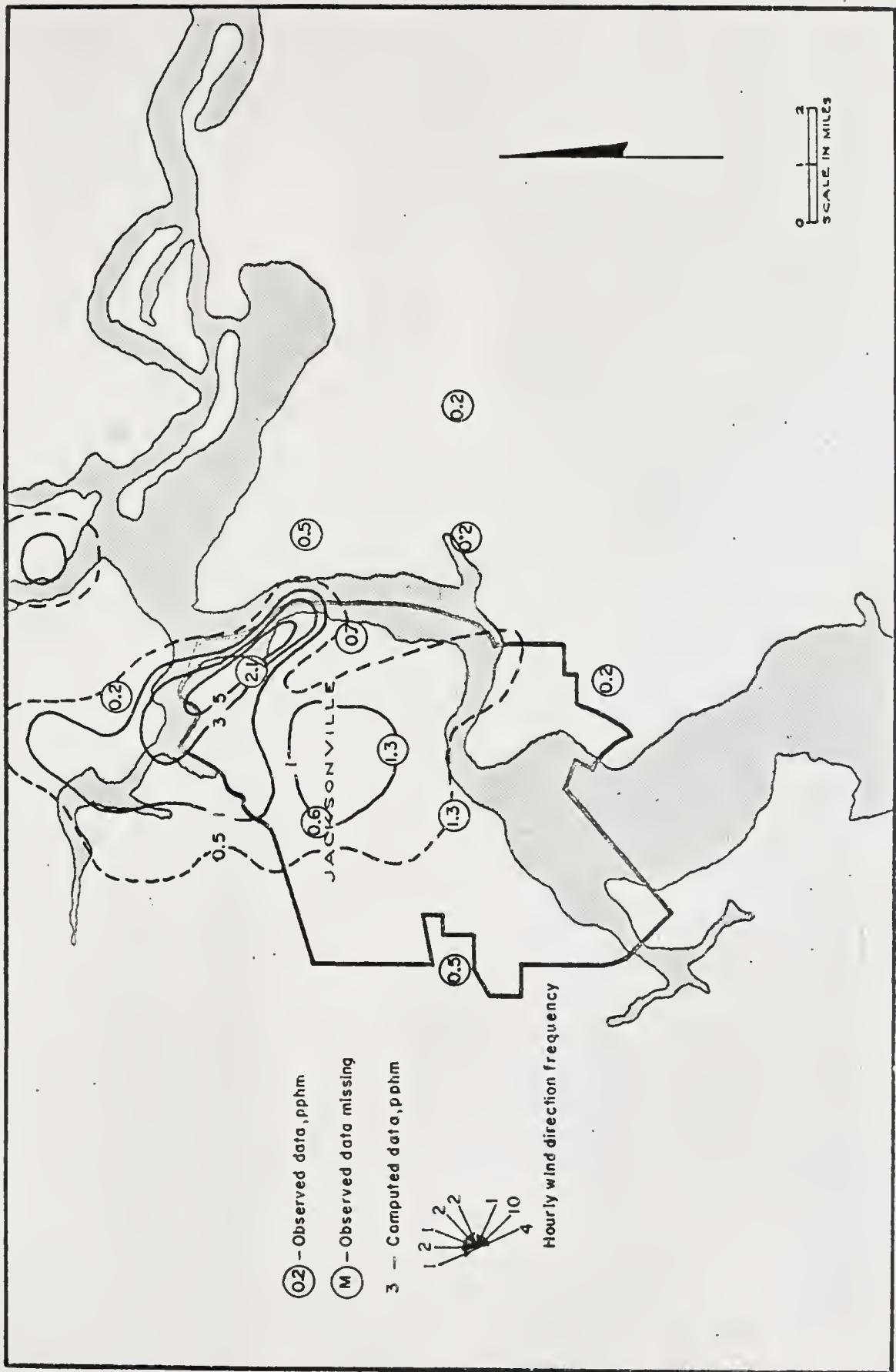


FIGURE 13—OBSERVED AND COMPUTED SO_2 CONCENTRATIONS FOR JAN. 13, 1966

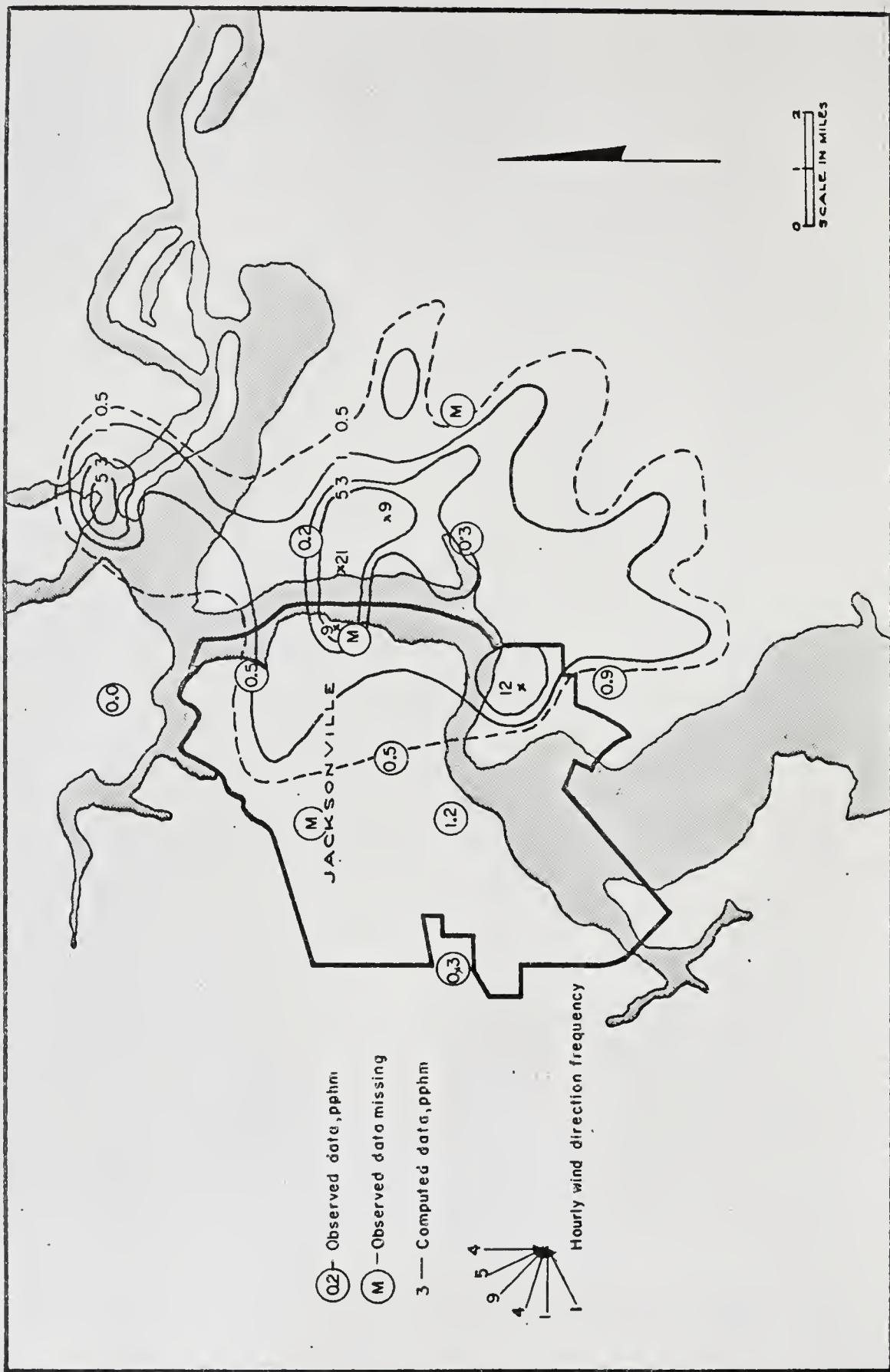


FIGURE 14—OBSERVED AND COMPUTED SO₂ CONCENTRATIONS FOR JAN. 16, 1966

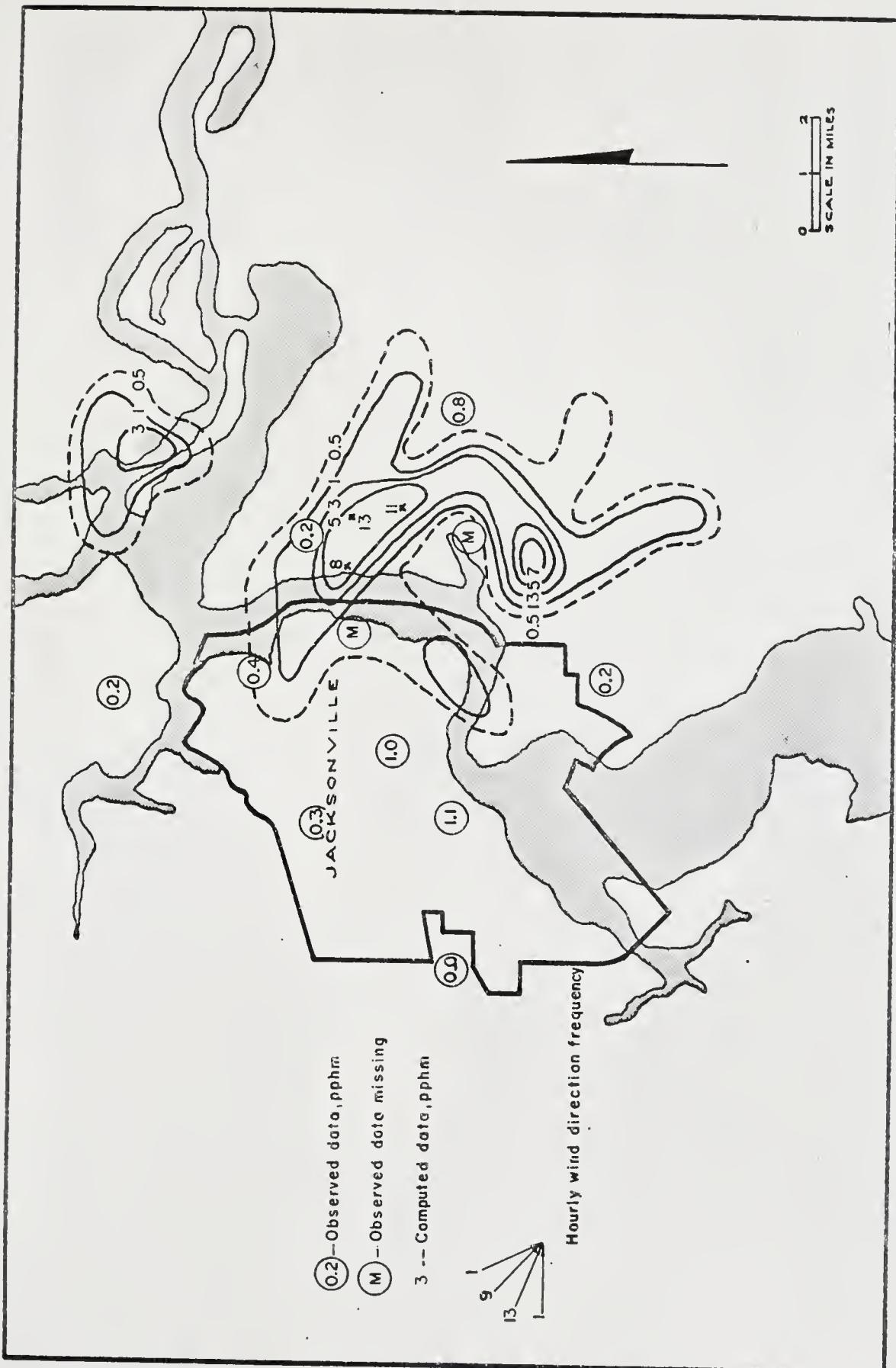


FIGURE 15- OBSERVED AND COMPUTED SO_2 CONCENTRATIONS FOR JAN. 18, 1966

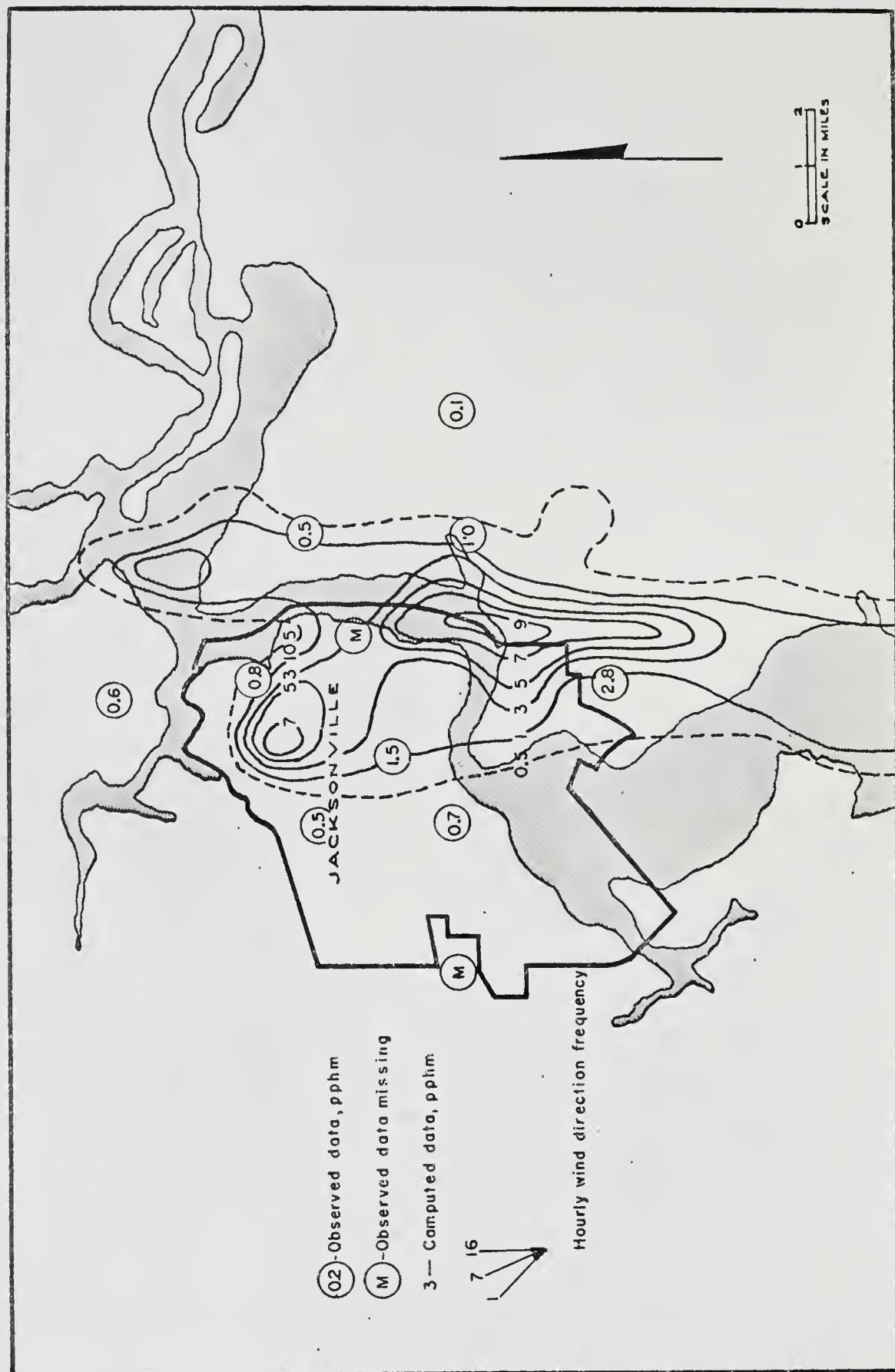


FIGURE 16—OBSERVED AND COMPUTED SO₂ CONCENTRATIONS FOR JAN. 20, 1966

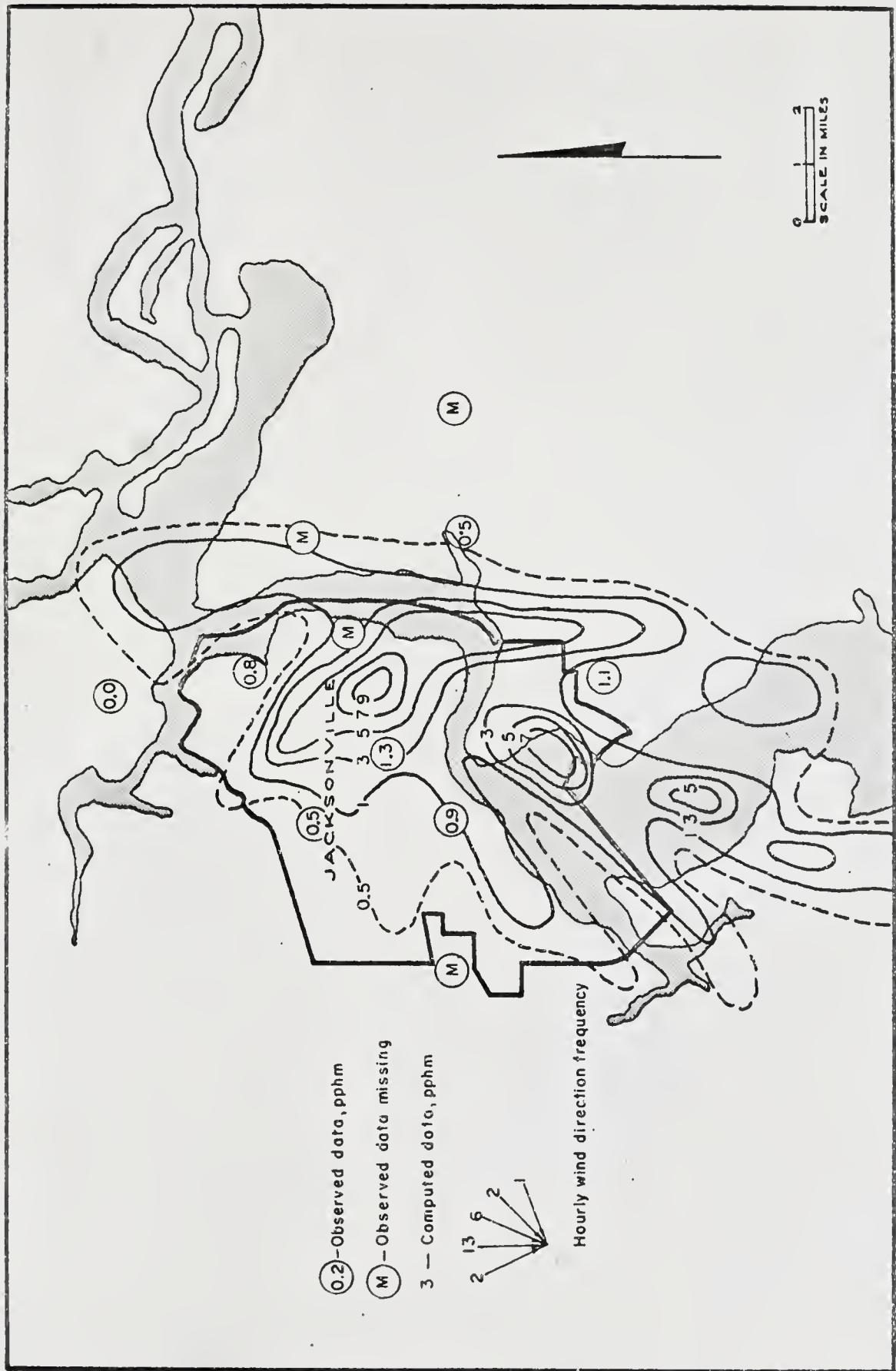


FIGURE 17—OBSERVED AND COMPUTED SO_2 CONCENTRATIONS FOR JAN. 25, 1966

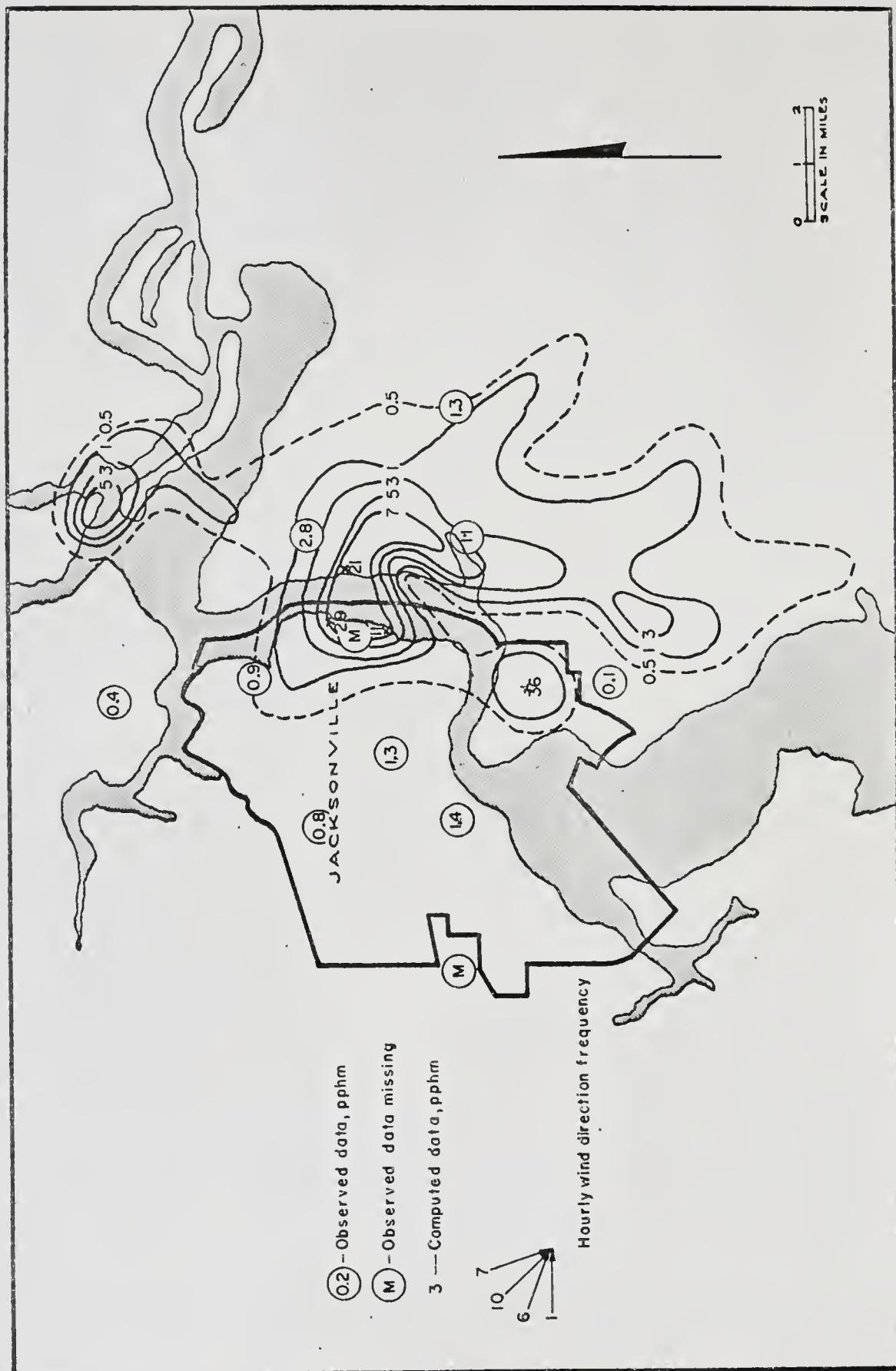


FIGURE 18—OBSERVED AND COMPUTED SO_2 CONCENTRATION FOR JAN. 27, 1966

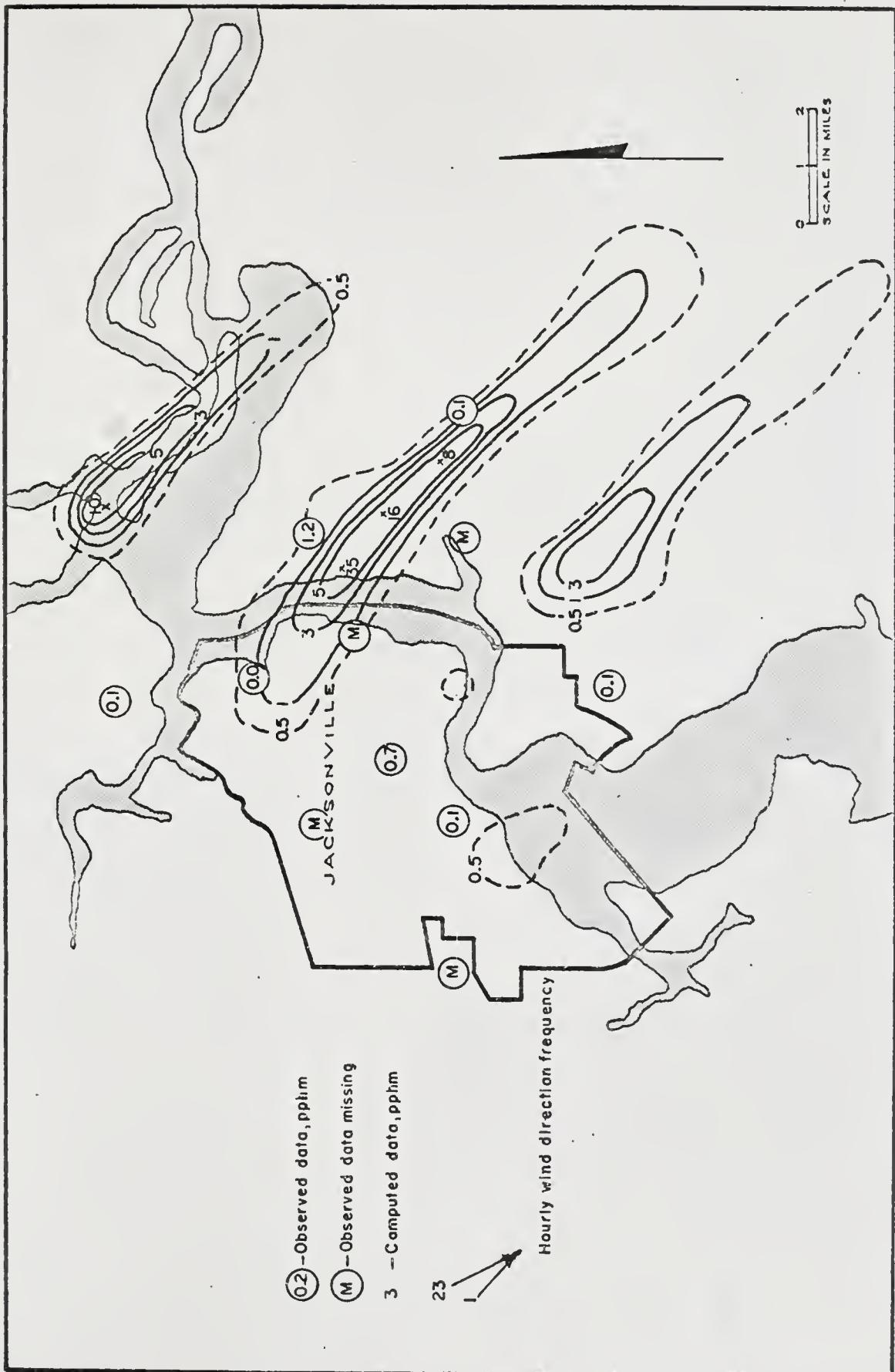


FIGURE 19—OBSERVED AND COMPUTED SO_2 CONCENTRATIONS FOR JAN. 30, 1966

contained in Appendix 3. These data were compared by:

1. The chi square test and the root mean square error.
2. Computing a skill score (72).
3. Comparing the number of computed concentrations within ± 0.5 pphm and within ± 1 pphm of the observed concentrations with respect to sampling days and sampling stations.
4. Computing the frequency of occurrence of computed and observed events.

The chi square test was used to test the goodness of fit of the computed concentrations compared to the observed concentrations. The number of computed concentrations occurring for each level of observed concentrations was compared with the number that would be expected in each category by chance. A chi square value of zero would indicate that the model predicted no better than chance, while values greater than zero would indicate that the model predicted better than chance. The degree of significance of the improvement over chance was determined from a table of chi square values. The larger the chi square value, the greater the improvement over chance.

While the chi square test determines the over-all significance of prediction, it does not test the number of

computed concentrations which agree exactly with the observed concentration. The skill score (72) was used to make this test. The number of computed concentrations agreeing with the observed concentration was compared with the number agreeing as expected by chance. A negative or zero skill score would indicate that the number of correct estimates is equal to or less than the number expected by chance, while a positive value would indicate an improvement over chance. The magnitude of the skill score indicates the degree of improvement over chance. A value of unity indicates perfect predictions.

By combining the results of the chi square test and the skill score, the accuracy of prediction of the model was determined. A significant chi square value and a positive skill score indicate an accuracy of prediction significantly better than chance. A negative or zero skill score with a significant chi square value indicates the accuracy expected by chance is significantly better than that of prediction.

The chi square test

The data presented in Table 8 were rounded to the nearest half pphm and to the nearest whole pphm, and contin-

gency tables were prepared. Based upon the marginal values of the contingency tables, "no relation" contingency tables were prepared (72). The "no relation" contingency table estimates results that could be expected if the observed sulfur dioxide concentrations were estimated using only the marginal values of the contingency table. These values represent the "expected" values of the chi square test. The contingency tables and corresponding "no relation" contingency tables are presented as Tables 9-12. The root mean square error of the data compared to the nearest half pphm (Table 9) is 0.76 pphm. The range of magnitude of the errors of these data is 0 to 4 pphm. The root mean square error of the data compared to the nearest whole pphm is 0.79 pphm. The range of the magnitude of the errors of these data is 0 to 4 pphm. These errors are in the range of the variance of the West-Gaeke method.

To satisfy the requirement of the chi square test that the value in every cell of a contingency table be equal to or greater than 5, some of the rows and columns of Tables 9-12 were combined. The resulting contingency tables are presented as Tables 13-16. Combining in this manner does not affect the validity of the chi square test.

The degrees of freedom for the chi square test are defined as $(r - 1)(c - 1)$ where r and c are the number of

TABLE 9

CONTINGENCY TABLE -- OBSERVED AND COMPUTED
 SULFUR DIOXIDE CONCENTRATIONS ROUNDED
 TO NEAREST HALF PPHM

Computed Conc. (pphm)	Observed Conc. (pphm)							Total
	0.0	0.5	1.0	1.5	2.0	2.5	3.0	
0.0	28	8	4	0	0	0	0	40
0.5	9	17	5	4	0	0	0	35
1.0	2	4	8	3	0	0	0	17
1.5	1	0	3	2	1	1	1	9
2.0	0	1	0	1	1	0	0	3
2.5	1	1	0	1	0	1	0	4
3.0	1	0	0	0	1	0	0	2
3.5	0	0	0	0	0	0	0	0
4.0	0	0	0	0	0	0	0	0
4.5	0	1	0	0	0	0	0	1
TOTAL	42	32	20	11	3	2	1	111

TABLE 10

NO RELATION CONTINGENCY TABLE -- OBSERVED AND COMPUTED
 SULFUR DIOXIDE CONCENTRATIONS ROUNDED
 TO NEAREST HALF PPHM

Computed Conc. (pphm)	Observed Conc. (pphm)							Total
	0.0	0.5	1.0	1.5	2.0	2.5	3.0	
0.0	14	12	7	4	1	1	1	40
0.5	13	10	6	4	1	1	0	35
1.0	7	4	3	2	1	0	0	17
1.5	3	3	2	1	0	0	0	9
2.0	1	1	1	0	0	0	0	3
2.5	2	1	1	0	0	0	0	4
3.0	1	1	0	0	0	0	0	2
3.5	0	0	0	0	0	0	0	0
4.0	0	0	0	0	0	0	0	0
4.5	1	0	0	0	0	0	0	1
TOTAL	42	32	20	11	3	2	1	111

TABLE 11

CONTINGENCY TABLE -- OBSERVED AND COMPUTED SULFUR DIOXIDE CONCENTRATIONS ROUNDED TO NEAREST WHOLE PPHM

Computed Conc. (pphm)	Observed Conc. (pphm)				Total
	0	1	2	3	
0	48	13	0	0	61
1	8	24	4	1	37
2	3	2	3	1	9
3	1	0	1	1	3
4	0	0	0	0	0
5	0	1	0	0	1
TOTAL	60	40	8	3	111

TABLE 12

NO RELATION CONTINGENCY TABLE -- OBSERVED AND COMPUTED SULFUR DIOXIDE CONCENTRATIONS ROUNDED TO NEAREST WHOLE PPHM

Computed Conc. (pphm)	Observed Conc. (pphm)				Total
	0	1	2	3	
0	32	23	4	2	61
1	20	13	3	1	37
2	5	3	1	0	9
3	2	1	0	0	3
4	0	0	0	0	0
5	1	0	0	0	0
TOTAL	60	40	8	3	111

TABLE 13

ADJUSTED CONTINGENCY TABLE -- OBSERVED AND COMPUTED
SULFUR DIOXIDE CONCENTRATIONS ROUNDED TO NEAREST
HALF PPHM

Computed Conc. (pphm)	Observed Conc. (pphm)			Total
	0	1	≥ 2	
0	28	8	4	40
1	9	17	9	35
2	2	4	11	17
≥ 3	3	3	13	19
TOTAL	42	32	37	111

TABLE 14

ADJUSTED NO RELATION CONTINGENCY TABLE -- OBSERVED
AND COMPUTED SULFUR DIOXIDE CONCENTRATIONS
ROUNDED TO NEAREST HALF PPHM

Computed Conc. (pphm)	Observed Conc. (pphm)			Total
	0	1	≥ 2	
0	14	12	14	40
1	13	10	12	35
2	7	4	6	17
≥ 3	8	6	5	19
TOTAL	42	32	37	111

TABLE 15

ADJUSTED CONTINGENCY TABLE -- OBSERVED AND COMPUTED
 SULFUR DIOXIDE CONCENTRATIONS ROUNDED
 TO NEAREST WHOLE PPHM

Computed Conc. (pphm)	Observed Conc. (pphm)		Total
	0	≥ 1	
0	48	13	61
1	8	29	37
≥ 2	4	9	13
TOTAL	60	51	111

TABLE 16

ADJUSTED NO RELATION CONTINGENCY TABLE -- OBSERVED
 AND COMPUTED SULFUR DIOXIDE CONCENTRATIONS
 ROUNDED TO NEAREST WHOLE PPHM

Computed Conc. (pphm)	Observed Conc. (pphm)		Total
	0	≥ 1	
0	32	29	61
.1	20	17	37
≥ 2	8	5	13
TOTAL	60	51	111

rows and columns respectively. Thus, the degrees of freedom for Tables 13 and 14 are $(3 - 1) (4 - 1)$ or 6 and for Tables 15 and 16 the degrees of freedom are $(2 - 1) (3 - 1)$ or 2.

The chi square value of the data compared to the nearest half pphm (Tables 13 and 14) is 57.53. This is greater than the chi square value at the 0.1 percent level (d.f. = 6) of 22.5. This indicates that the probability of the model predicting better than chance is 99.9 percent. The chi square value of the data compared to the nearest whole pphm is 37.71. This value is also significant at the 0.1 percent level (χ^2 at 0.1 percent with two degrees of freedom is 13.8).

Skill score

The skill score (72) is defined as

$$S = \frac{R - E}{T - E}$$

where

S = the skill score,

R = the number of correct estimates,

E = the number of expected correct estimates (from the "no relation" contingency table), and

T = the total number of estimates.

The skill score computed from the data compared at the nearest half pphm (Tables 9 and 10) is 0.35, and that computed from data compared at the nearest whole pphm (Tables 11 and 12) is 0.46. Coupled with the significant results of the chi square test, these positive skill scores indicate that the accuracy of prediction of the model is significantly better than chance (72) at both levels of comparison.

Number of computed concentrations within ± 0.5 pphm and ± 1 pphm of the observed concentration

The number of computed concentrations within ± 0.5 pphm and within ± 1 pphm of the observed concentration presented with respect to sampling days (Table 17) and with respect to sampling stations (Table 18).

The effect of the daily frequency of occurrence of stability classes and the average daily wind speed were considered when comparing the data with respect to sampling days (Table 17). The wind direction direction distribution for the sampling days is presented in Figures 8-19. There appeared to be no relationship between the number of over-calculations and undercalculations and the wind speed or degree of atmospheric stability. The greatest number of

TABLE 17

NUMBER OF COMPUTED CONCENTRATIONS WITHIN SPECIFIED LIMITS
OF OBSERVED CONCENTRATION WITH RESPECT TO DAY OF SAMPLING

Date	Frequency of Occurrence of Stability Classes (5/4/3/2/1)	Average Wind Speed (mph)	Limits \pm 0.5 pphm			Limits \pm 1 pphm		
			Low	Correct	High	Low	Correct	High
12/26/65	• •	• •	1	10	0	0	11	0
1/4/66	.08/.84/.08/0/0	6.5	1	10	0	0	11	0
1/6/66	0/.75/.25/0/0	6.7	0	9	2	0	10	1
1/9/66	.21/.50/.25/.04/0	5.8	0	9	1	0	10	0
1/11/66	.38/.29/.33/0/0	5.5	1	6	1	0	7	1
1/13/66	.25/.46/.17/.08/.04	4.5	1	10	0	0	11	0
1/16/66	0/.33/.63/.04/0	6.7	1	5	2	0	6	2
1/18/66	0/.71/.21/.08/0	4.4	0	8	1	0	8	1
1/20/66	0/.87/.13/0/0	7.1	1	8	0	1	8	0
1/25/66	0/.87/.13/0/0	7.0	0	6	1	0	7	0
1/27/66	0/.29/.67/.04/0	8.8	4	5	0	0	9	0
1/30/66	0/.25/.54/.21/0	10.5	0	5	2	0	7	0
AVG. FOR JAN., 1966	.14/.54/.28/.04/0	6.7	10	91	10	1	105	5
		TOTAL						

TABLE 18

NUMBER OF COMPUTED CONCENTRATIONS WITHIN SPECIFIED
 LIMITS OF OBSERVED CONCENTRATION WITH
 RESPECT TO SAMPLING STATIONS

Station	Limit \pm 0.5 pphm			Limit \pm 1 pphm		
	Low	Correct	High	Low	Correct	High
E1	0	9	1	0	9	1
E2	0	8	3	0	8	3
E3	1	11	0	1	11	0
E4	1	7	1	0	9	0
W6	1	8	0	0	9	0
W7	4	7	0	0	11	0
W8	0	11	1	0	12	0
W9	0	7	0	0	7	0
W11	1	4	1	0	5	1
W12	2	8	2	0	12	0
W14	0	11	1	0	12	0
TOTAL	10	91	10	1	105	5
PERCENTAGE OF TOTAL	9	82	9	1	95	4

undercalculations exceeding 0.5 pphm appeared in the data for January 27; but, on January 16, a day with similar meteorological conditions, there were one undercalculation and two overcalculations. Therefore these errors could not be explained in terms of meteorological conditions. All of the undercalculations for these two days were in the range 0.5 to 1 pphm, which is within the deviation of the West-Gaeke method, so the errors are not considered significant.

A comparison of data with respect to sampling stations (Table 18) revealed that at Station E2 the computed concentration was higher than the observed concentration by more than 1 pphm on three occasions. This would indicate that either the station was physically protected from normal airflow patterns or that the emission inventory in this area was overestimated. The exact cause of this discrepancy was not ascertained.

The number of computed concentrations correct within the limits of comparison is 82 percent correct within \pm 0.5 pphm and 95 percent correct within \pm 1 pphm.

Frequency of occurrence of computed
and observed events

An interesting method of presenting the data is with respect to the percentage of the time an event occurred. Table 19 presents the percentage of the time an observed concentration occurred in each category, and Table 20 presents the percentage of the time a computed concentration occurred in each category. These tables were prepared from the columns and rows of Table 11 respectively.

From these tables it can be observed that 80 percent of the zero concentrations observed were computed correctly, whereas 79 percent of the computed zero concentrations were correct. The computed concentrations were correct 65 percent of the time at the 1 pphm level, 33 percent of the time at the 2 pphm level, and 34 percent of the time at the 3 pphm level. Observed concentrations were computed correctly 60 percent of the time at the 1 pphm level, 38 percent of the time at the 2 pphm level, and 33 percent of the time at the 3 pphm level.

Discussion

When comparing concentrations computed by the model with observed conditions, one should remember that during the time period selected for the input parameters and over

TABLE 19
FREQUENCY OF OCCURRENCE OF OBSERVED EVENTS

Computed Conc. (pphm)	Observed Conc. (pphm)			
	0	1	2	3
0	80	32	0	0
1	13	60	50	33
2	5	5	38	33
3	2	0	12	34
4	0	0	0	0
5	0	3	0	0
TOTAL	100	100	100	100

TABLE 20
FREQUENCY OF OCCURRENCE OF COMPUTED EVENTS

Observed Conc. (pphm)	Computed Conc. (pphm)					
	0	1	2	3	4	5
0	79	21	33	33	0	0
1	21	65	23	0	0	100
2	0	11	33	33	0	0
3	0	3	11	34	0	0
TOTAL	100	100	100	100	0	100

the entire area encompassed by the model, the conditions for computation were assumed to be invariant. This is to say that the wind direction was from 1 of 16 discrete directions and the wind speed was constant, that the emission rates of all sources were constant, and that the atmospheric stability was constant. These are compromising assumptions to make for a system as dynamic as the atmosphere over an urban area, but were necessary for practical reasons. Because of these assumptions, individual computed values may be extremely high or low. These values should not be completely disregarded, but should be considered with the realization that it is the computed concentration pattern over the entire urban area that is of paramount importance.

In the treatment of the data, a regression analysis was not made because the variability of the method of obtaining the observed concentrations (±1.8 pphm at the 95 percent C.L.) was nearly the same magnitude as the range of observed concentrations (1 to 3 pphm). Thus, the results of a regression analysis would be meaningless.

Applications of the Model

Several effects were studied contingent to the development of the model and to illustrate some applications of the model.

Contaminant decomposition rate

The rate of decomposition of sulfur dioxide is dependent upon several factors, including temperature, humidity, sunlight, and catalytic substances. No quantitative relationship exists, however, between these factors and the rate of decomposition. Gartrell, Thomas, and Carpenter (66) reported that for measurements made within a plume emitted from a coal-fired power generating station, the half life of sulfur dioxide averaged about four hours. Since conditions in Jacksonville appear quite favorable for the decomposition of sulfur dioxide, the effect of a 3-hour and a 2-hour half life was compared with the effect of the reported 4-hour half life. The data for January 20 were used for this study. It was found that the maximum change in concentration for the three conditions was 0.1 pphm. Thus for the conditions tested, the effect of variations in the half life was insignificant. This result can be explained by the fact that the sources adding most to the concentration at

a receptor are near the receptor and because of this the travel time to the receptor is short. Because of the short travel time the amount of decomposition, and hence the reduction in concentration, is small. For days with very light wind speeds the effect of half life variation might be more pronounced.

Relative effect of areal and point sources

The contribution of the areal and point sources to the sulfur dioxide concentration in Jacksonville was determined by first reading in zero emissions for a 24-hour period for the point sources and then zero emissions for the same period of time for the areal sources. This was done using the data for January 20. Computed concentration isopleths for the two conditions are shown in Figures 20 and 21. Figure 16 shows the composite of these two effects.

The maximum concentration contributed by areal sources is 0.3 pphm or about 3.5 percent of the maximum computed concentration shown in Figure 16. In Jacksonville it appears that most of the sulfur dioxide in the atmosphere results from the emissions of the point sources.

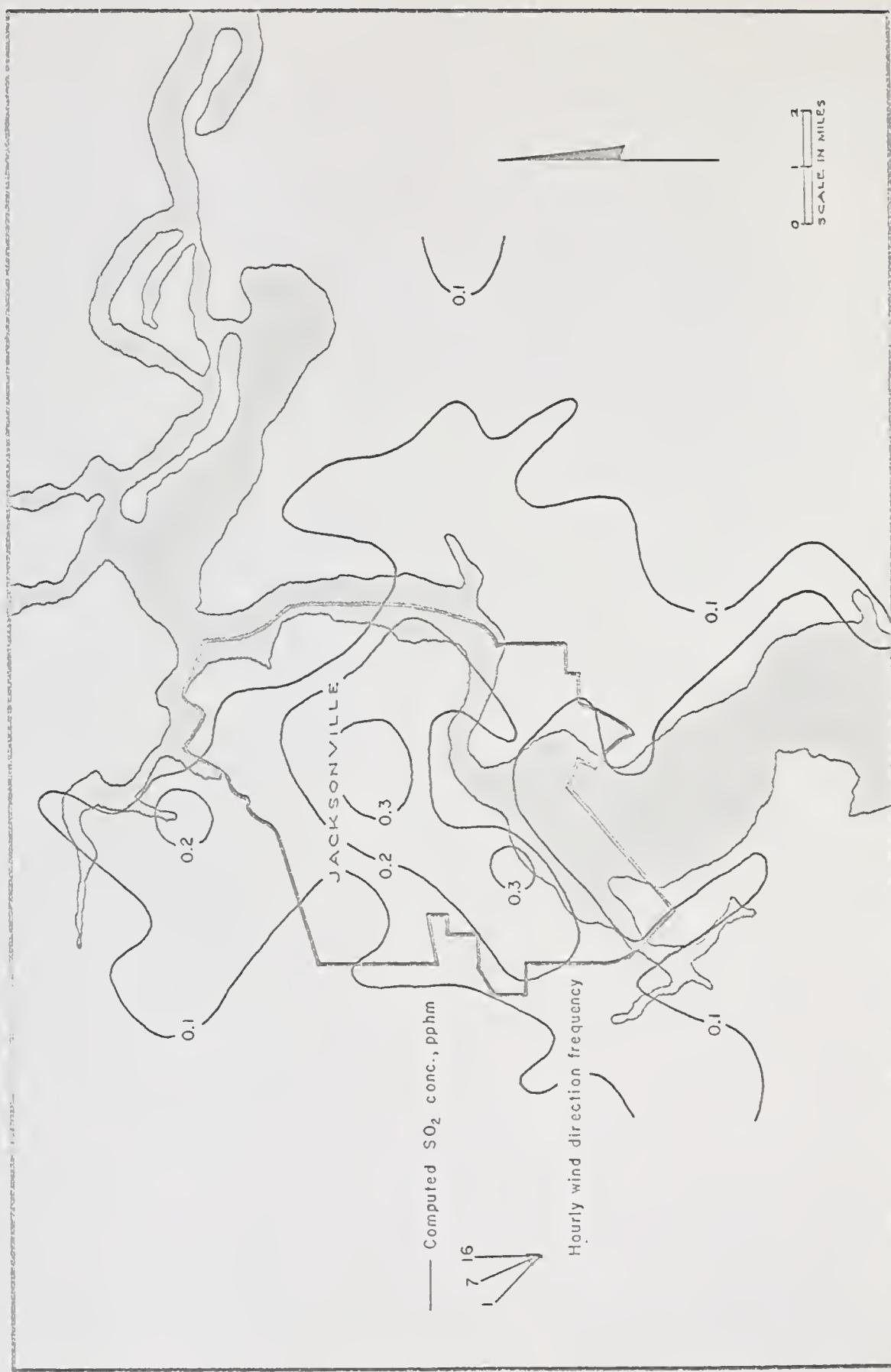


FIGURE 20-AREAL SOURCE CONTRIBUTION TO SO_2 CONCENTRATION OF JAN. 20, 1966

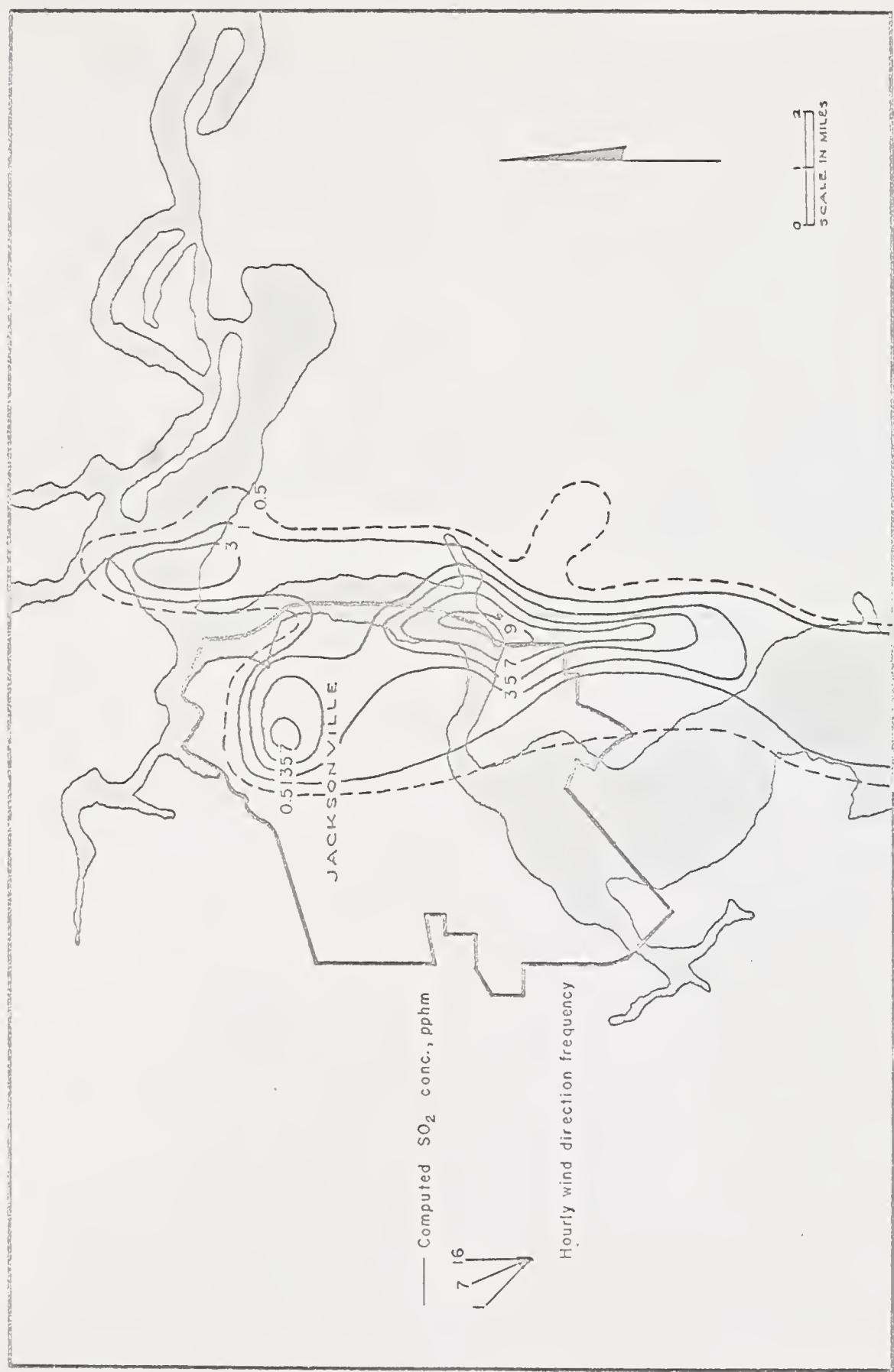


FIGURE 21-POINT SOURCE CONTRIBUTION TO SO₂ CONCENTRATION OF JAN.20,1966

Effect of reducing point source emission rates

Since the major portion of the sulfur dioxide was contributed by point sources and because there is an effort being made to reduce ambient sulfur dioxide levels by reducing the sulfur content of fuels, a study was made to see what effect a reduction in point source emissions would have on the sulfur dioxide level. The emission rates of all point sources were reduced by a 25 and 50 percent increment for January 20. The results are presented in Figures 22 and 23 respectively. The 25 percent increment resulted in a reduction of the maximum ground level concentration of about 29 percent but did not significantly reduce the area affected by threshold concentrations. The 50 percent increment resulted in a reduction of the maximum ground level concentration of about 54 percent and also began to reduce the area affected by threshold concentrations.

The nearly direct relationship between emission rate reduction and sulfur dioxide concentration reduction results from the fact that the point sources contribute such a large proportion of the total ground level concentration. This direct relationship should not be considered applicable to all urban areas.

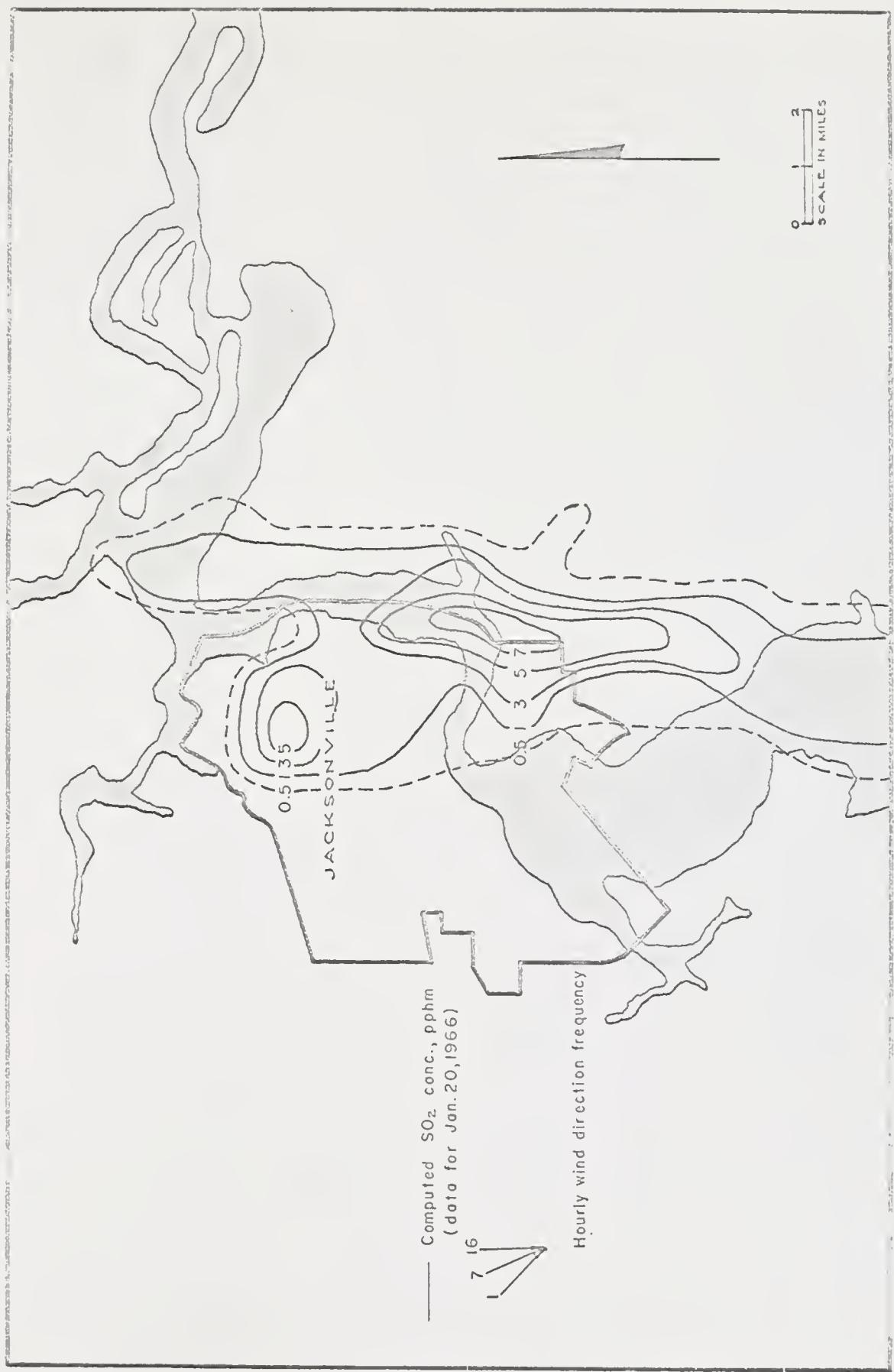


FIGURE 22-EFFECT OF A 25% REDUCTION OF POINT SOURCE EMISSION RATES

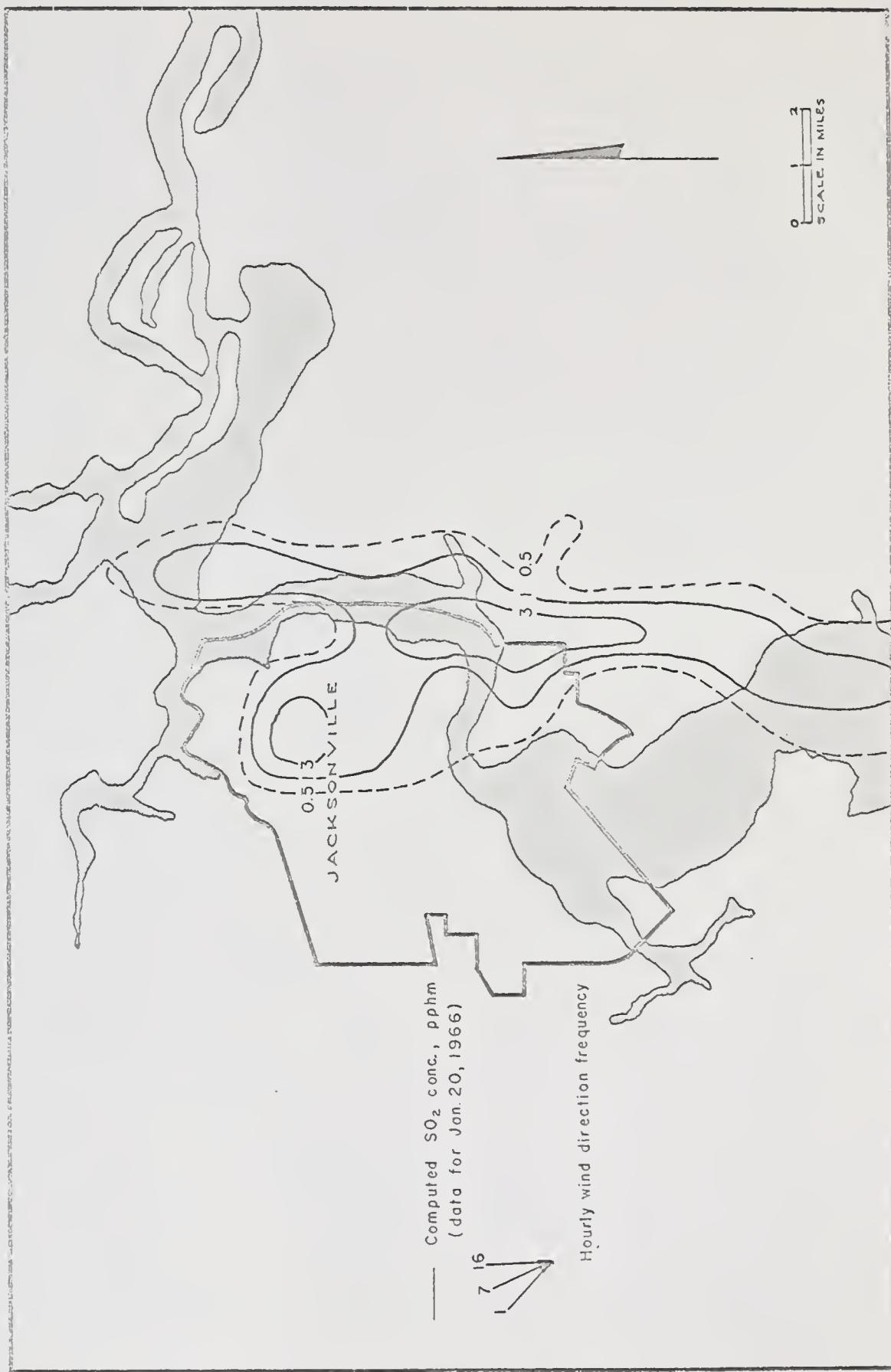


FIGURE 23-EFFECT OF A 50% REDUCTION IN POINT SOURCE EMISSION RATES

Effect of an additional source

An electric power generating station is being constructed in northeastern Duval County. It was desired to know what effect the sulfur dioxide emissions from this new source would have on the area. The estimated emission rate from this source was included in the data for January 20. Figure 24 shows that for the conditions of January 20 the new generating station would affect an area to the south of it with a maximum concentration of 2 pphm. For a complete study of this type, the effect of the power station would have to be determined for several combinations of wind direction, wind speed, and atmospheric stability, seeking the most adverse conditions.

Reduction of emission rates of electric power generating stations

Utility officials in the Jacksonville area have given consideration to making a conversion from oil to natural gas on several existing boilers and further to having gas firing capability in new units under construction. The effect of this change on the ambient sulfur dioxide concentration was assessed with the model. Using the data for January 20, the emission rates of the existing and new power stations were reduced to simulate the change to

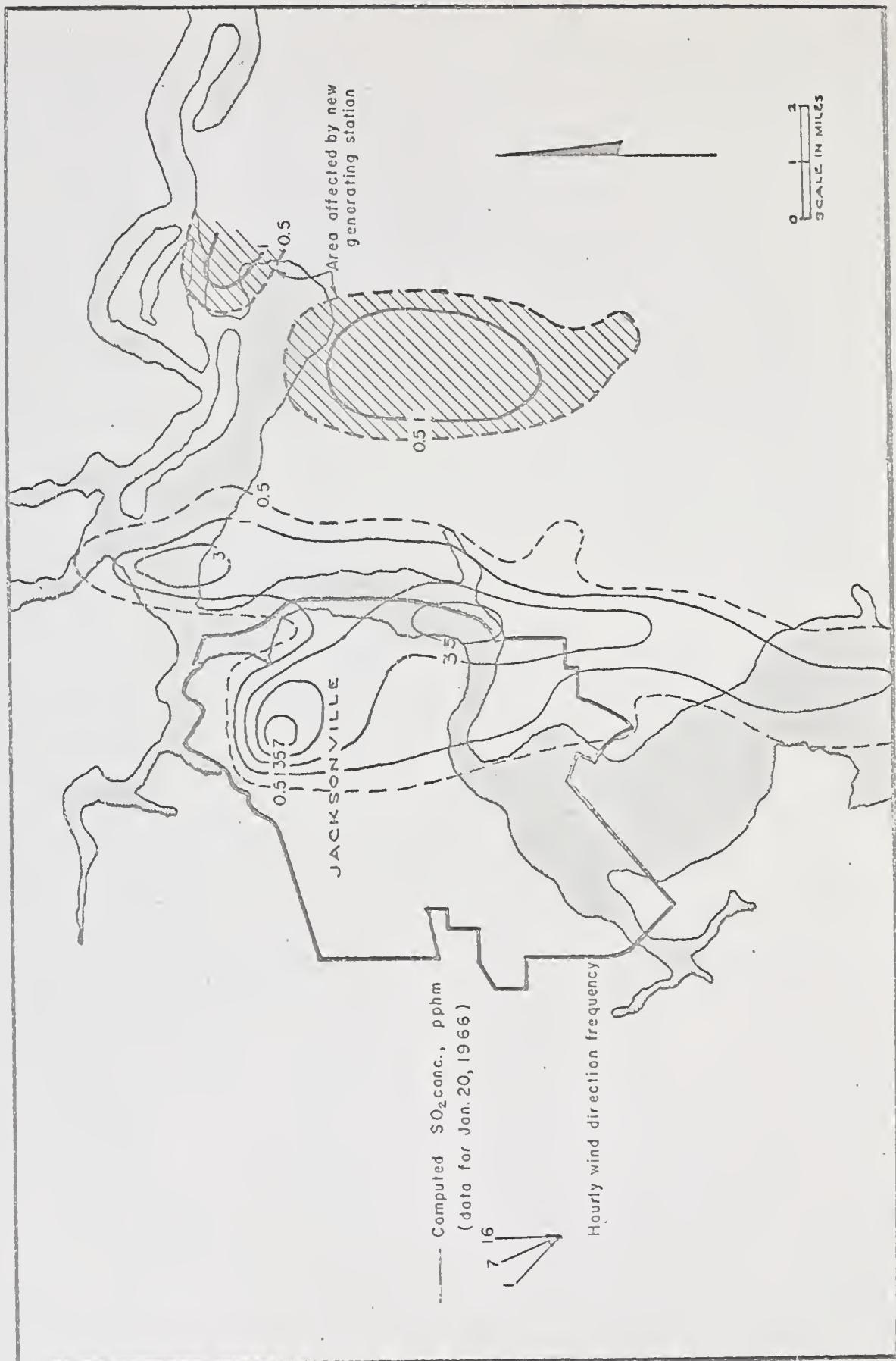


FIGURE 24—EFFECT OF THE ADDITION OF A NEW POWER GENERATING STATION

natural gas. The proposed three gas fired units could have supplied the power demand of January 20 except for the period from 1900 to 2100 hours. During this period oil fired units would have been required to meet the additional power demand. The results of this change on the ambient sulfur dioxide concentration are presented in Figure 25. The sulfur dioxide concentration in south Jacksonville was reduced from a maximum of 9 pphm to 1 pphm and in the area affected by the new power station (Figure 24) the concentration was reduced to less than 0.5 pphm. Thus, the proposed change from oil to gas fired boilers would considerably reduce the sulfur dioxide concentration in some parts of Duval County.

Evaluation of the monthly sulfation pattern

The lead dioxide candle is used extensively for studying exposure patterns to various gaseous sulfur compounds because of the economy and simplicity of the method. The results from the lead candles are reported in the units of micro-grams SO_3 /square centimeter/day. Attempts have been made to relate these units to an average sulfur dioxide concentration with the units of parts per million. The relationship has been reported to be approximately 0.25 pphm

for one micro-gram SO_3 /square centimeter/day (73).

The conditions for the 11 sampling days in January, 1966, were examined to see if it would be justifiable to compare the average sulfur dioxide concentration for these 11 days to the monthly results from the lead candles in order to obtain a concentration-sulfation rate relationship. The frequency distribution of wind speed, wind direction, and occurrence of atmospheric stability classes for the entire month and the 11 days were compared. The wind data for the two periods are in Appendix 4. Wind roses of these periods are presented in Figure 26. The wind patterns for these periods are almost identical. The frequency distribution of the stability classes 5,4,3,2,1 for the month was 0.14 : 0.54 : 0.28 : 0.04 : 0.00. The frequency distribution of the stability classes for the 11 days was 0.09 : 0.56 : 0.30 : 0.05 : 0.00. These distributions are significant at the 90 percent confidence level when tested by the chi square test.

The number of degrees declination from 65°F for the month of January, 1966, was 1323°F or 42.6°F declination/day. The declination from 65°F for the 11 days was 534°F or 48.6°F declination/day. This difference was not considered significant since temperature affected primarily the

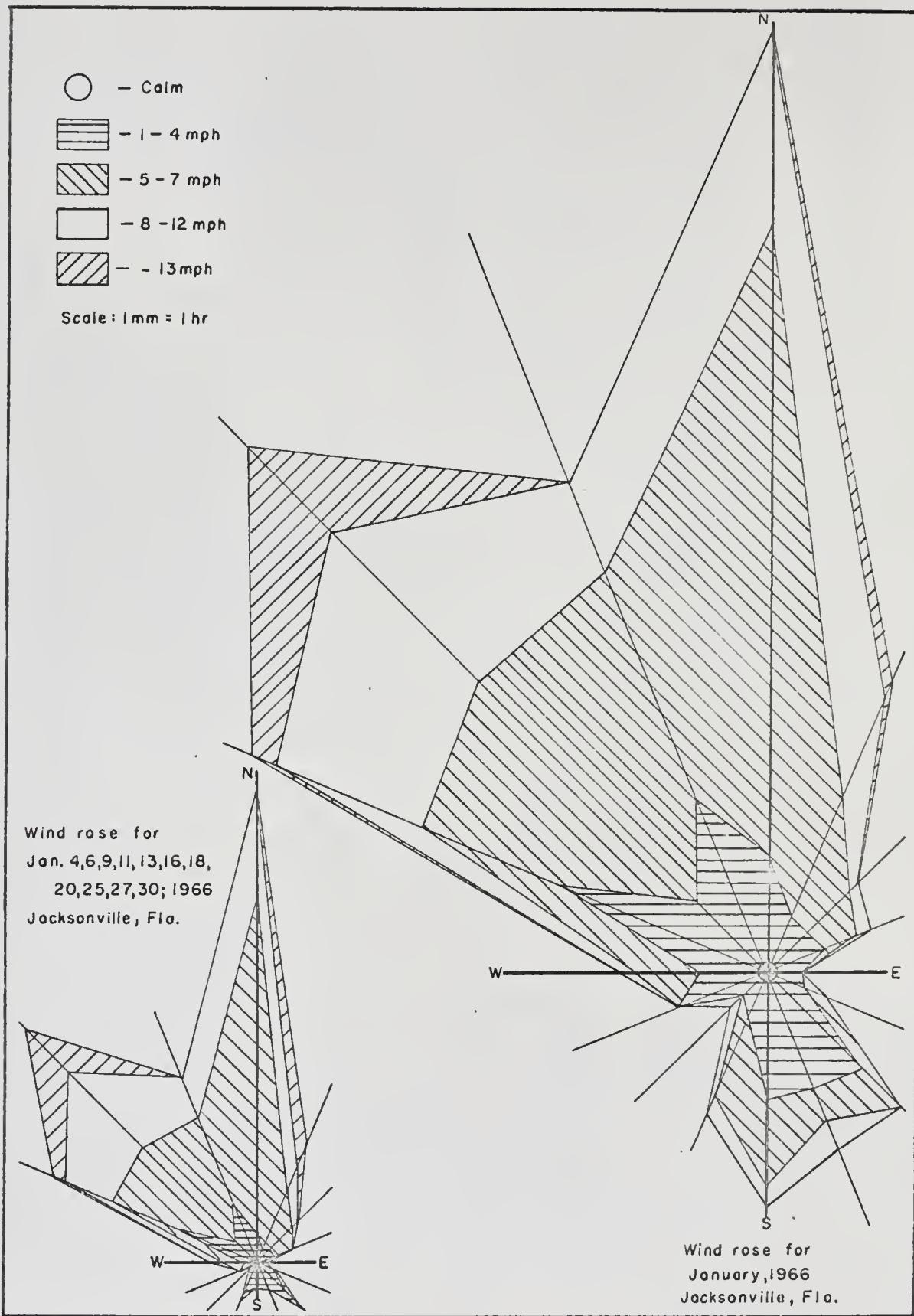


FIGURE 26-WIND ROSE FOR JAN., 1966, AND FOR DAYS OF SAMPLING IN JANUARY

emission rate from areal sources, and the effect of these sources is small when compared with the effect of point sources. Four of the 11 days were weekend days and 7 were week days. As a result of these comparisons it was considered justifiable to assume the average sulfur dioxide concentration for the 11 days could be used as an estimator of the average monthly concentration. The average concentration was then compared with the monthly sulfation pattern as determined by the lead dioxide candle sampling network (Figure 27). The patterns do not coincide well, indicating the presence of sulfur compounds, other than sulfur dioxide, in the atmosphere. (The emission inventory [63] showed that a substantial amount of hydrogen sulfide was released from various sources in the area.) A plot of the observed sulfation rate by the lead candle method and the corresponding computed monthly average sulfur dioxide concentration are presented in Figure 28.

The equation for the line of best fit to these data is

$$SO_2 = 0.12 + 0.21S$$

where

S = the sulfation rate, micrograms SO_3 /square centimeter/day, and

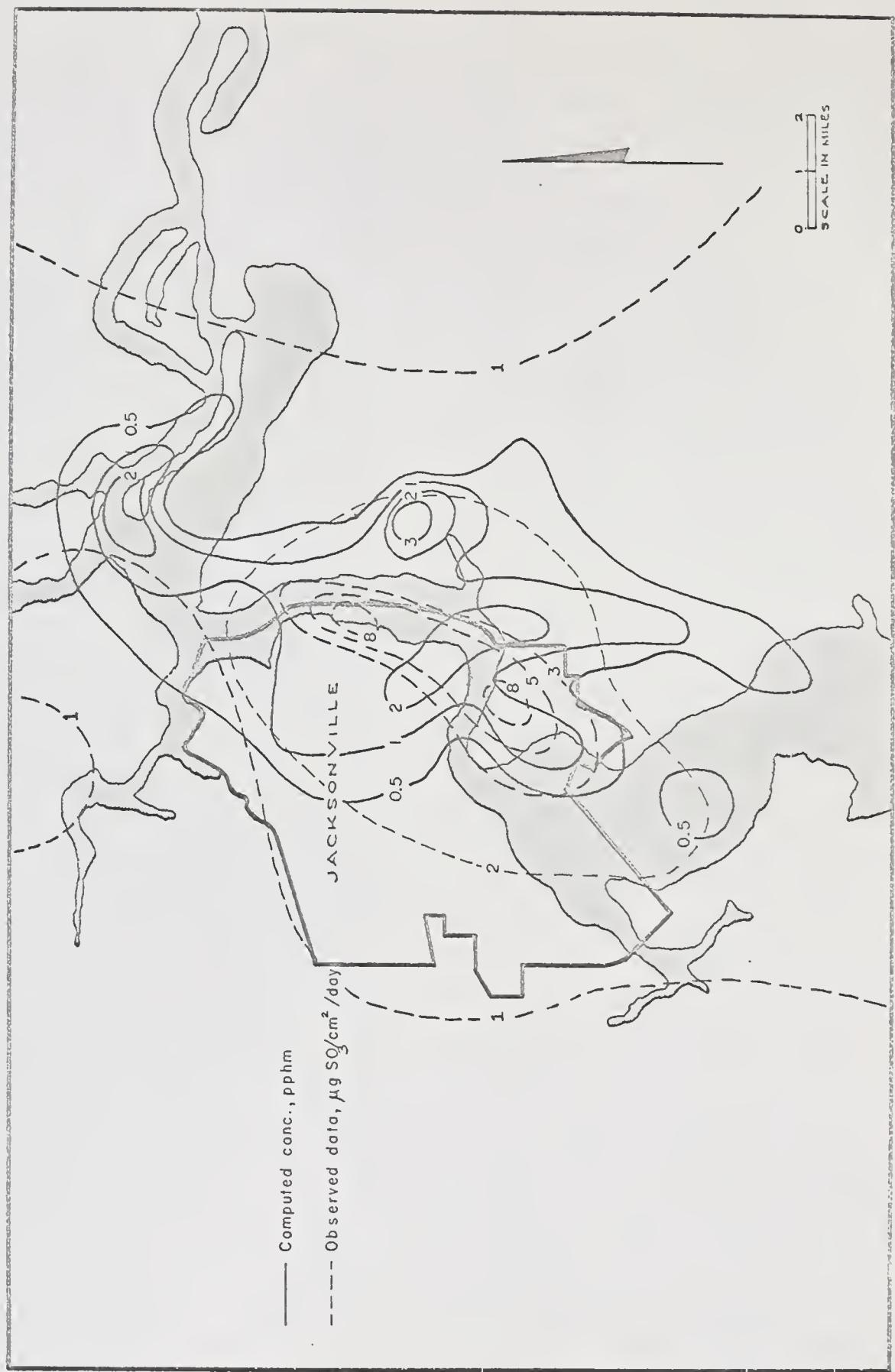


FIGURE 27-SULFATION PATTERN AND MONTHLY AVERAGE SO_2 CONCENTRATION FOR JANUARY, 1966

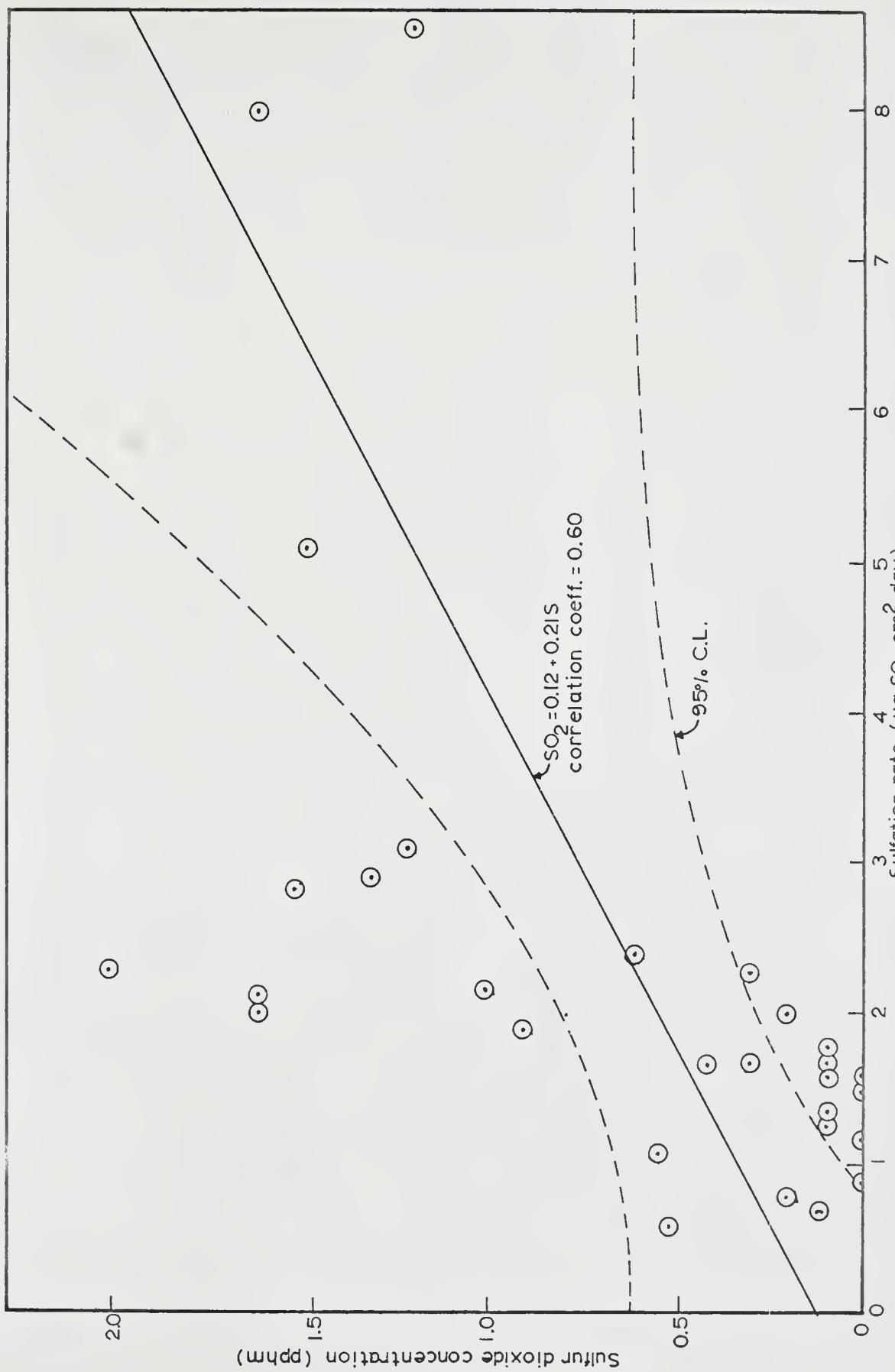


FIGURE 28—RELATIONSHIP BETWEEN SULFATION RATE AND SO_2 CONCENTRATION

SO_2 = the ground level sulfur dioxide concentration, pphm.

The correlation coefficient r for these data is 0.60. The fraction of the variance in the data explained by regression is equal to r^2 , i.e., 0.36 or 36 percent. Thus, 64 percent of the variance is due to unexplained errors and reactions between sulfur compounds other than sulfur dioxide and the lead candles. Since the relative quantities of sulfur compounds in the atmosphere are continually changing, this relationship will not remain constant. For conditions existing in Jacksonville, Florida, during January, 1966, the relationship between sulfation rate and sulfur dioxide concentration as determined from the slope of the curve in Figure 28 is

1 micro-gram SO_3 /square centimeter/day
= 0.21 pphm.

As seen by the confidence limits in Figure 28, the variance of this value is quite large. Therefore it appears that a well-defined relationship between sulfation rate and sulfur dioxide concentration does not exist.

Ground level concentration
from a drifting plume

The contribution to the ground level concentration of an airborne pollutant one time period after emission from the source is dependent primarily upon wind speed and to a lesser extent on atmospheric stability. The wind speed is the primary factor because concentration is a function of the rate of transport of the pollutant. The rate of transport in turn controls the residence time of the pollutant at the receptor. Since the average ground level concentration is a time-concentration function, the shorter the residence time the lower will be the concentration. Therefore, with high wind speeds the contribution from a drifting plume would be expected to be less than with low wind speeds.

The atmospheric stability controls the vertical and horizontal crosswind dispersion of the drifting plume. An unstable atmosphere causes more dispersion, which results in a larger area being affected but with an attenuated peak concentration. With a stable atmosphere the area affected is smaller but the peak concentration is more extreme. The limited data available to assess the effect of wind speed on the contribution of the drifting plume to the ground

level concentration were only for periods of slightly stable and neutral stability classifications. Thus, the effect of atmospheric stability could not be determined. The available data included the results of computations with simulated values and data from December 9, 1965. The percentage of contribution of the drifting plume to the ground level concentration was determined for each time period and tabulated with the wind speed of the previous and current time period and atmospheric stability classification (Table 21).

TABLE 21
RELATIVE GROUND LEVEL CONCENTRATION FROM A
DRIFTING PLUME

Percentage of Contribution from Drifting Plume	Wind Speed (mph)		Average Stability Classification
	Time Period T	Time Period T+1	
6	4	3	4
5	3	4	5
6	3	3	5
12	3	2	4
9	2	3	4
9	2	1	4
30	1	1	4

These data were plotted as percentage of contribution versus the inverse product of the wind speeds of the two time periods (Figure 29). The latter factor was selected because the wind speed inversely affects the ground level concentration in both the previous and current time period (see section entitled Effect of a Drifting Plume for discussion). The curve was fitted to the data by fixing the point (0,0) and minimizing the errors to the other points. The point (0,0) was fixed, since physically no contribution is possible with infinite wind speeds. The expression for this curve is

$$C = \frac{33.5}{u_T \cdot u_{T+1}}$$

where

C = the percentage of contribution to the ground level concentration from a drifting plume,

u_T = the wind speed of the previous time period, miles/hour, and

u_{T+1} = the wind speed of the current time period, miles/hour.

This indicates that for periods of very light winds the contribution to the ground level concentration from a drifting plume might be as much as 33 percent.

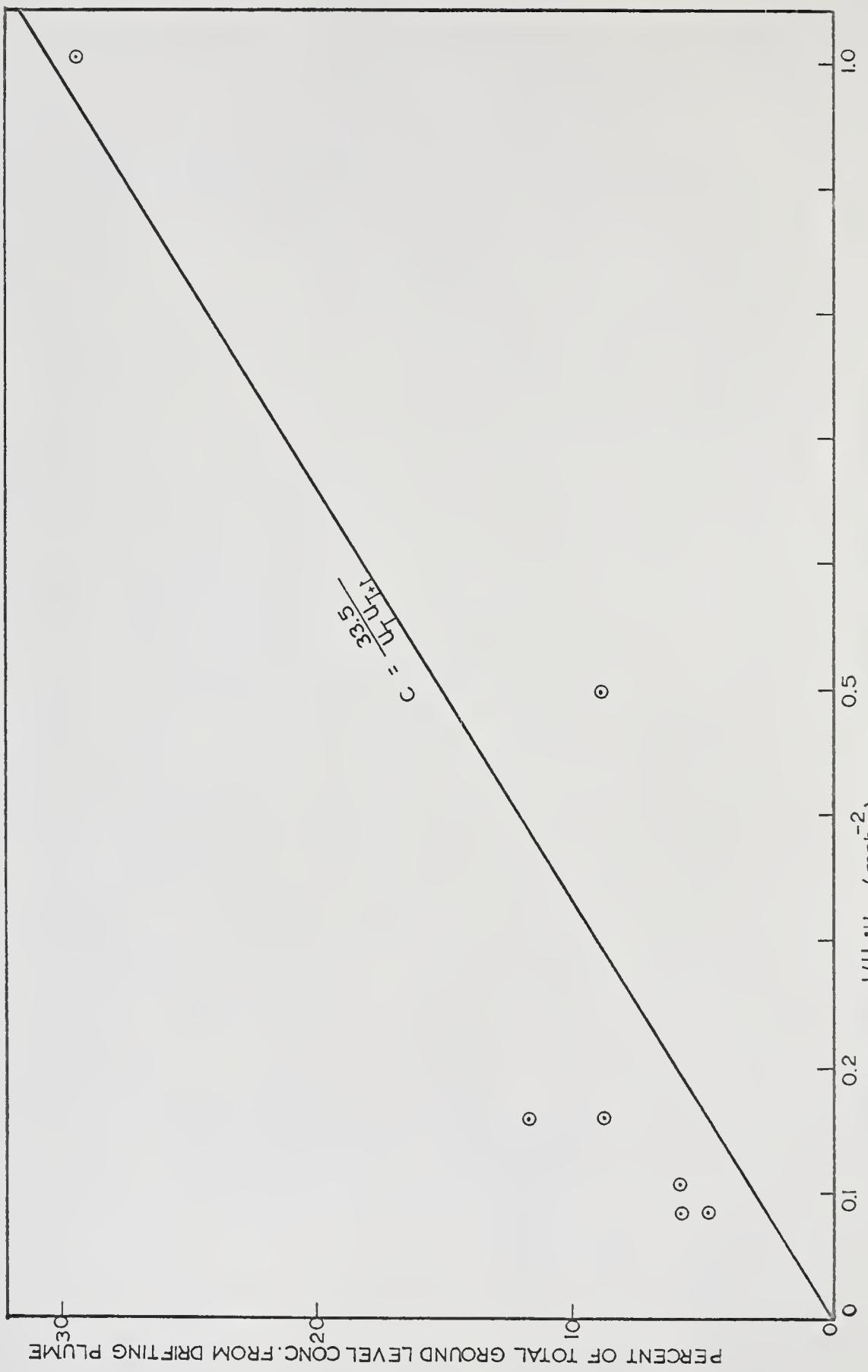


FIGURE 29--GROUND LEVEL CONCENTRATION FROM A DRIFTING PLUME

CHAPTER VI

SUMMARY

The basis of the dispersion model is the Gaussian dispersion equation. This equation and modifications thereof were applied reiteratively to areal and point sources within a 15- by 15-mile area to determine the cumulative effect of gaseous pollutants from all sources upon 225 receptors within the area. A 15- by 15-mile grid system subdivided into 1-mile increments defines the areal sources and receptors. The model accounts for the effects of wind speed, wind direction, atmospheric stability, and source emission rate. These factors can be averaged over any integral multiple of an hourly period from 1 to 24 hours. The output of the model, the ground level pollutant concentration, can be averaged over any integral multiple of an hourly period without limitation. Other features of the model are: (1) the model accounts for a pollutant one time period after emission from the source, (2) only the receptors within the downwind range of the source, as defined by

the product of wind speed and travel time, are affected by emissions from the source, (3) the plume rise is considered to be a function of downwind distance, (4) the vertical dispersion of the plume is limited by discontinuities in the vertical stability structure, (5) the decomposition of a pollutant is accounted for by an exponential decay function, and (6) the wind speed is assumed to be a logarithmic function of height.

The most limiting assumption made in the development of the model was that there is no spatial variation in the meteorological parameters. For Jacksonville this assumption was found to be valid (62) but reports on other urban areas have shown considerable variation in these parameters (74).

Topographical features were not accounted for within the model. Where tested, this presented no difficulty since the terrain was basically level. If applied in areas of extreme terrain features, the accuracy of the model might not be as good.

The model was tested in Jacksonville, Florida, using observed sulfur dioxide concentrations and meteorological data for December, 1965, and January, 1966. These data were collected as part of the Greater Jacksonville Air Pollution Control Program. A sulfur dioxide emission inventory was

accounting for emissions from dwellings, commercial and industrial sources, and institutions. Twenty-four-hour average sulfur dioxide concentrations, determined by the West-Gaeke method, were available from 11 sampling stations for 12 days during the test period. The range of observed concentrations was 0 to 3 pphm. Monthly sulfation patterns determined by the lead dioxide candle method were also available. Computed 24-hour-average concentrations were compared with the 111 observed values to the nearest half pphm and to the nearest whole pphm. Eighty-two percent of the computed values were within \pm 0.5 pphm of the observed values, 9 percent were high by more than 0.5 pphm, and 9 percent were low by more than 0.5 pphm. When compared to the nearest whole pphm, 95 percent were within \pm 1 pphm, 4 percent were high by more than 1 pphm, and 1 percent were low by more than 1 pphm. The accuracy of prediction of both sets of results was found to be significant at the 0.1 percent level when tested by the chi square test.

Several examples were used to illustrate some applications of the model. These included: (1) assessing the effect of the rate of pollutant decomposition in the atmosphere, (2) assessing the relative contribution of areal sources (dwellings and small sources) and point sources

(emission rate greater than 10,000 grams SO_2 /hour) to the ambient sulfur dioxide concentration, (3) assessing the effect of additional sources, (4) assessing the effect of reducing emission rates, and (5) comparing the monthly sulfation pattern to the monthly average sulfur dioxide concentration. From the latter, a very poorly defined relationship between sulfation rate and sulfur dioxide concentration was determined; i.e., 1 micro-gram SO_3 /square centimeter/day is equivalent to an average sulfur dioxide concentration of 0.21 pphm.

The accuracy of this model demonstrates that dispersion models are feasible and can be quite reliable. The model must be used judiciously, however, and with reliable emission and meteorological data. If so used, dispersion models have a great potential in many phases of air pollution control programs.

The development of this model has pointed out the necessity of additional research in several areas. These include:

1. A more thorough study of atmosphere dispersion in an urban area.
2. A study of the effect of urban areas of various sizes upon meteorological conditions surrounding the area.

3. A study of the areal and vertical wind patterns under various conditions in an urban area.
4. The development of a dispersion model to describe particulate dispersion.
5. The development of a functional expression to describe plume rise.
6. A study of the factors affecting the decomposition of pollutants in the atmosphere.

APPENDIX 1

A MULTIVARIABLE ATMOSPHERIC DISPERSION MODEL

```
DIMENSION AREA(5,5), Q(15,15,5), U(25), KSTAB(24),
1 DIR(25), DIRVEL(2,24), KEY(15,15), BETA(15,29),
2 CHIG(15,29,5), ZPHY(15,15,5), DY(15,29,5), IMISS(24),
3 DX(15,29,5), SN(16), X(15,29), R(15,15,5), S(15,15,5),
4 CSN(16), MU(4), MJ(50), NB(50), TQ(15,15,5), BIM(24),
5 TOP(24), CHI(15,15), NU(50), TCHI(15,15,3), CX(15,29),
6 CICQ(40,40), SIGN(15,29), HALIV(24)
COMMON ACHI, AM13, AM34, AM0, AM, AN13, AN34, AN,
1 ARFAC, A, BRG, B, BX, BY, C, DAY, DECA, DELTA, DELZ,
2 DIRANG, DIRI, DIRT, DI, DK, DL, DM, DN, D,
3 EFFZ, E, EXT, F1, F2, F3, F4, FACT, FJUN, F, G, H,
4 IB, IDAY, ICIR, IHRA, IHRP, IH, II, IIS, IKE, IOTA,
5 IQUAD, I, IS, ISTAB, ISUM, ITIME, IT, IU, IYR, JIM,
6 JJ, JJS, JUN, J, JS, KAPA, KAR, KAT, KEX, KMISS, KODE,
7 KONT, KCX, KOY, KT, LAMBDA, LIMN, LIM, LIN, LL, LCK,
8 LOT, LGX, L, MAN, MDIST, ML, MM, MU, MR, M, MTEMP,
9 MTHAVG, MI, MUM, NDIST, NLIM, NN, NO, N, NS, NIEMP
COMMON NT, NUMDAY, NUM, O, PLUME, P, RR, S12, S13,
1 S24, S34, SIGY, SIGZ2, SIGZI, SIGZK, SIGZ, SR, TEMPQ,
2 TEMP, THETA, TNG, T, UIM, UIN, UKM, UKN, UMI, UM2,
3 UM3, UM4, UN1, UN2, UN3, UN4, V, W, XLN, Y1INT, Y1,
4 Y1S, Y2INT, Y2, Y2S, YR, Y, YY, Z2, ZH, ZOS, Z, ZZ,
5 AREA, BETA, BTM, CHIQ, CHI, CICQ, CSN, CX, DIR,
6 DIRVEL, DX, DY, IMISS, KEY, KSTAB, MJ, MU, NB, NU,
7 Q, R, SIGN, SN, S, TCHI, TOP, TQ, U, X, ZPHY, HALIV
      READ INPUT TAPE 5, 1000, AREA
1000 FORMAT( 25F2.2 )
      READ INPUT TAPE 5, 1012, CSN
1012 FORMAT( 16F4.2 )
      READ INPUT TAPE 5, 1013, SN
1013 FORMAT( 16F4.2 )
      READ INPUT TAPE 5, 1, N, (I,J,M, (R(I,J,M), S(I,J,M),
                                ZPHY(I,J,M), K=1, N)
1 FORMAT( 14/(3I2,3F4.0) )
      READ INPUT TAPE 5, 1015, ((KEY(I,J), I=1, 15), J=1, 15)
1015 FORMAT( 72I1 )
      READ INPUT TAPE 5, 1007, KODE, KONT, MTHAVG, NUMDAY, ITIME
1007 FORMAT( 5I2 )
```

IDENTIFICATION OF INPUT CONSTANTS

AREA - RELATIVE EFFECT FACTORS FOR THE EFFECT OF

EMISSIONS FROM AN AREAL SOURCE UPON A RECEPTOR
AT THE CENTER OF THE AREA

CSN - COSINE FUNCTIONS OF WIND DIRECTION ANGLES
SN - SINE FUNCTIONS OF WIND DIRECTION ANGLES
N - THE NUMBER OF POINT SOURCES BEING CONSIDERED.
R - EAST(+) - WEST(-) DISPLACEMENT OF POINT SOURCE
I, J, M FROM THE CENTER OF GRID AREA I, J (METERS)
S - NORTH(+) - SOUTH(-) DISPLACEMENT OF POINT SOURCE
I, J, M FROM THE CENTER OF GRID AREA I, J (METERS)
ZPHY - PHYSICAL STACK HT. OF SOURCE I, J, NS (METERS)
I, J - N-S AND E-W COORDINATES OF THE GRID SYSTEM
M - SOURCE NUMBER OF SOURCE WITHIN AREA I, J. AREAL
SOURCE IS 1, PT. SOURCES ARE 2 THRU N.
KEY - THE NUMBER OF SOURCES IN AREA I, J.
KODE - NUMBER OF HOURS OVER WHICH OUTPUT IS TO BE
AVERAGED.
KONT - A KEY DEPENDING UPON THE CONTAMINANT
=1 FOR SULFUR DIOXIDE
=2 FOR OXIDES OF NITROGEN
=3 FOR FLUORIDES
=4 FOR HYDROCARBONS
=5 FOR OXIDANTS
MTHAVG - A SWITCH
= 1 IF LONG TERM AVERAGE OUTPUT IS NOT REQUIRED
= 2 IF OUTPUT IS TO BE AVERAGED OVER THE TOTAL
NUMBER OF DAYS READ IN
NUMDAY - THE NUMBER OF DAYS OF DATA THAT ARE READ
ITIME - THE NUMBER OF HOURS OVER WHICH THE METEOROLOGICAL
DATA IS AVERAGED (RANGE IS 1-24)

```

DIR(25) = 0.0
U(25) = 0.0
DO 2 I=1,15
DO 2 J=1,15
2 TCHI(I,J,3) = 0.0
ISUM = 1
MAN = (NUMDAY*24)/KODE
KMISS = 0
10 JIM = 0
JON = 0
LIM = 0
LIN = 0
LOX = 0
DO 11 I=1,15
DO 11 J=1,15
TCHI(I,J,1) = 0.0
CHI(I,J) = 0.0
DO 11 NS=1,5
11 Q(I,J,NS) = 0.0
READ INPUT TAPE 5, 1001, HALIV
1001 FORMAT (24F3.1)
READ INPUT TAPE 5,1002, KSTAB

```

```

1002 FORMAT( 24I2 )
  READ INPUT TAPE 5, 1003, TOP
1003 FORMAT( 24F3.0 )
  READ INPUT TAPE 5, 1014, BTM
1014 FORMAT( 24F3.0 )
  READ INPUT TAPE 5,1004, YR, AMO, DAY, ((DIRVEL(I,J),
                                         I=1,2),J=1,12)
1004 FORMAT ( 2X,F2.0,2X,26F2.0,14X )
  READ INPUT TAPE 5,1009, ((DIRVEL(I,J),I=1,2),J=13,24)
1009 FORMAT ( 10X,24F2.0,14X )
  DO 5 IT = 1,24
    DIR(IT) = DIRVEL(1,IT)
    5 U(IT) = DIRVEL(2,IT)
333 LOK = 1
  LOT = 1
  6 READ INPUT TAPE 5, 1005, IHRA
1005 FORMAT( I2 )
  READ INPUT TAPE 5, 1006, ((Q(I,J,1),I=1,15),J=1,15)
1006 FORMAT(8F7.0,16X)
  999 GO TO (7,8),LOT
    7 READ INPUT TAPE 5,1010,IHRP
1010 FORMAT(I2)
  READ INPUT TAPE 5,1011, N,(I,J,NS,(Q(I,J,NS)),K=1,N)
1011 FORMAT ( I4/(I2,I2,I1,F7.0,60X))

```

IDENTIFICATION OF INPUT DATA

HALIV - THE DECOMPOSITION HALF LIFE OF CONTAMINANT
 IN HOURS
 KSTAB - THE HOURLY ATMOSPHERIC STABILITY CLASSIFICATION
 TOP - THE BASE OF AN UPPER INVERSION IN HUNDREDS
 OF FEET
 BTM - THE HEIGHT TO THE TOP OF INVERSIONS BASED AT
 OR NEAR THE GROUND IN HUNDREDS OF FEET (SET
 BTM=100 IF NO INVERSION EXISTS)
 DIRVEL - 12 ONE HOUR VALUES OF WIND SPEED (MPH) AND WIND
 DIRECTION (16 PT. COMPASS WITH DIRECTION OF A
 CALM=17).
 YR,AMO - YEAR, MONTH, AND DAY ON WHICH THE WIND SPEED
 DAY AND DIRECTION ARE OBSERVED.
 IHRA - THE HOUR THRU WHICH THE AREAL SOURCE EMISSION
 RATES ARE CONSTANT
 Q(I,J,1) - THE EMISSION RATE FOR AREAL SOURCE I,J (GRAMS
 /HOUR)
 IHRP - THE HOUR THRU WHICH THE POINT SOURCE EMISSION
 RATES ARE CONSTANT
 Q(I,J,NS) - THE EMISSION RATE FOR POINT SOURCE I,J,NS
 (GRAMS/HOUR)

```

8 KAT = 1
  GO TO (12,14),LCK
12 LL=1

```

```
14 DO 50 IT=LL,24
      IF(IT-IHRP)375,15,375
15 IF(DIR(IT))20,20,21
20 LIM = LIM+1
      LIN = LIN+1
      IMISS(LIM) = IT*100
      JIM = JIM+1
      GO TO 47
21 IU = U(IT)
      ISTAB = KSTAB(IT)
      CALL CREA
      IF(U(IT))750,750,58
58 IF(DIR(IT)-3.0)60,60,61
60 IQUAD = 1
      GO TO 70
61 IF(DIR(IT)-7.0)62,62,63
62 IQUAD = 2
      GO TO 71
63 IF(DIR(IT)-11.0)64,64,65
64 IQUAD = 3
      GO TO 72
65 IF(DIR(IT)-16.0)66,60,750
66 IQUAD = 4
      GO TO 73
70 IF(DIR(IT)-16.0)704,74,750
704 DIRT = DIR(IT)
      GO TO 75
74 IDIR = 4
      GO TO 76
71 DIRT = DIR(IT) - 4.0
      GO TO 75
72 DIRT = DIR(IT) - 8.0
      GO TO 75
73 DIRT = DIR(IT) - 12.0
75 IDIR = DIRT
      IF(IDIR)74,74,76
76 CALL DARP
      CALL PTIN
750 IF(IT-ITIME)176,176,177
176 KT = 25
      GO TO 178
177 KT = IT-ITIME
178 GO TO (226,227,228,229,230), ISTAB
226 A = 10.81
      C = -4.07
      D = 0.495
      E = 0.25
      G = 350.0
      EXT = 1.10
      GO TO 180
```

```

227 A = 3.82
    C = -1.25
    D = 0.20
    E = 0.43
    G = 110.0
    EXT = 1.16
    GO TO 180
228 A = -2.28
    C = 1.00
    D = -0.011
    E = 0.62
    G = 60.0
    EXT = 1.22
    GO TO 180
229 A = -3.27
    C = 1.23
    D = -0.038
    E = 0.66
    G = 30.0
    EXT = 1.29
    GO TO 180
230 A = -3.87
    C = 1.38
    D = -0.052
    E = 0.67
    G = 25.0
    EXT = 1.34
180 IF(U(KT)-10.)179,179,45
179 IF(DIR(KT))45,45,280
280 IF(DIR(KT)-17.0)181,250,250
181 IF(DIR(IT))45,45,182
182 IF(DIR(IT)-17.0)183,240,240
183 DIRK = DIR(KT)+8.0
    IF(DIRK-16.0)185,185,184
184 DIRK = DIRK-16.0
185 DIRI = DIR(IT)+8.0
    IF(DIRI-16.0)585,585,584
584 DIRI = DIRI-16.0
585 DELTA = CIRK-DIRI
    KAPA = DELTA
    IF(KAPA)586,265,587
586 KAPA = KAPA+16
587 IF(KAPA-8)186,250,588
588 KAPA = 16-KAPA
186 BRG = 13.0-DIRI
    IOTA = BRG
    IF(IOTA)187,187,188
187 IOTA = 16+IOTA
188 UIN = U(IT)*SN(IOTA)
    NU(1) = UIN
    UIM = U(IT)*CSN(IOTA)
    MU(1) = -UIM

```

```

    IF(NU(1))190,189,190
189 IF(MU(1))190,240,190
190 BRG = 17.0-DIRK
      LAMBDA = BRG
192 UKN = U(KT)*CSN(LAMBDA)
      NU(2) = -UKN
      UKM = U(KT)*SN(LAMBDA)
      MU(2) = -UKM
      IF(NU(2))194,193,194
193 IF(MU(2))194,250,194
194 CALL DRIFTA
      GO TO 45
240 CALL DRIFTB
      GO TO 45
250 CALL DRIFTC
      GO TO 45
265 CALL DRIFTD
45 JON = JON+1
      DO 52 I=1,15
      DO 52 J=1,15
      CHI(I,J) = CHI(I,J) + TCHI(I,J,1)
      TCHI(I,J,2) = TCHI(I,J,1)
52 TCHI(I,J,1) = 0.0
47 IF(JIM-KODE)49,48,48
48 IF(JIM-LIN)484,484,44
484 KMISS = KMISS+1
44 FJON = JON
      DO 521 I=1,15
      DO 521 J=1,15
521 CHI(I,J)=CHI(I,J)*1C00000./(FJON*(FLOATF(KODE))**0.15)
5210 WRITE OUTPUT TAPE 6, 2010
2010 FORMAT(1H1,////////,35X,54HGROUND LEVEL CONCENTRATION,
      IN MICROGRAM
      1S/CUBIC METER,/37X,50HAT THE CENTER OF GRID AREA I,J
      FOR THE CONTAMINANT
      GO TO(301,302,303,304,305),KONT
301 WRITE OUTPUT TAPE 6, 2011
2011 FORMAT( 55X, 14HSULFUR DIOXIDE /)
      GO TO 310
302 WRITE OUTPUT TAPE 6, 2012
2012 FORMAT( 53X, 18HOXIDES OF NITROGEN /)
      GO TO 310
303 WRITE OUTPUT TAPE 6, 2013
2013 FORMAT( 57X, 9HFLUORIDES /)
      GO TO 310
304 WRITE OUTPUT TAPE 6, 2014
2014 FORMAT( 56X, 12HHYDROCARBONS /)
      GO TO 310
305 WRITE OUTPUT TAPE 6, 2015
2015 FORMAT( 56X, 8HOXIDANTS /)
310 MO = AMO

```

```

IDAY = DAY
IYR = YR
WRITE OUTPUT TAPE 6, 2000, KODE, IT, MO, IDAY, IYR
2000 FORMAT( 36X, 8HFOR THE 13, 20H HOUR PERIOD ENDING 12,
9H00 HOURS 1
12, 1H/12, 3H/1912, //// 55X, 12H) COORDINATE / 15X, 6H
(WEST) 93X,
26H(EAST) / 18X, 1H1 6X, 1H2 6X, 1H3 6X, 1H4 6X, 1H5 6X,
1H6 6X,
31H7 6X, 1H8 6X, 1H9 6X, 2H10 5X, 2H11 5X, 2H12 5X, 2H13
5X, 2H14 5
4X, 2H15 / 6X, 7H(NORTH) //)
WRITE OUTPUT TAPE 6, 2001, ((CHI(I,J),J=1,15),I=1,15)
2001 FORMAT( 12X, 3H1 15F7.0// 12X, 3H2 15F7.0 // 12X, 3H3
15F7.0//
112X, 3H4 15F7.0 // 8X, 7H1 5 15F7.0 // 8X, 7H2 6
15F7.0 /
28X, 1H0 / 8X, 7H0 7 15F7.0 / 8X, 1H1 / 8X, 7H3 8
15F7.0 /
38X, 1H1 / 8X, 7H4 9 15F7.0 / 8X, 1H2 / 8X, 7H5 10
15F7.0 / 8X,
41H6 / 11X, 4H11 15F7.0 // 11X, 4H12 15F7.0 // 11X,
4H13 15F7.0
5// 11X, 4H14 15F7.0 // 11X, 4H15 15F7.0 / 6X, 7H
(SOUTH) //
611X, 78H HOURS DURING WHICH DATA IS MISSING (FROM 100
HOURS TO END
70F CURRENT PERIOD) - // )
WRITE OUTPUT TAPE 6, 2002, (IMISS(L), L=1,LIM)
2002 FORMAT( 11X, 12I5 / 11X, 12I5 )
DO 379 I=1,15
DO 379 J=1,15
TCHI(I,J,3) = CHI(I,J) + TCHI(I,J,3)
379 CHI(I,J) = CHI(I,J)/12.9
WRITE OUTPUT TAPE 6, 1314
1314 FORMAT(1H1,////)
WRITE OUTPUT TAPE 6, 1315, ((CHI(I,J),J=1,15),I=1,15)
1315 FORMAT(//20X,15F5.1)
GO TO (46,378),MTHAVG
378 IF(ISUM-MAN)372,376,375
376 DO 374 I=1,15
DO 374 J=1,15
374 CHI(I,J) = TCHI(I,J,3)/FLOATF(ISUM-KMISS)
KODE = 24*NUMDAY
ISUM = ISUM+1
IMISS(1) = 0
LIM = 1
GO TO 5210
372 ISUM = ISUM+1
46 JON = 0
LIN = 0
JIM = 0

```

```

DO 373 I=1,15
DO 373 J=1,15
373 CHI(I,J) = 0.0
49 IF(IT-IHRA)56,57,57
56 IF(IT-IHRP)50,561,561
561 LOK = 2
  DO 562 I=1,15
  DO 562 J=1,15
  NUM = KEY(I,J)
  DO 562 NS=2,NUM
562 TQ(I,J,NS) = Q(I,J,NS)
  GO TO 7
57 IF(IT-IHRP)571,572,572
571 LOK = 2
  LOT = 2
  DO 575 I=1,15
  DO 575 J=1,15
575 TQ(I,J,1) = Q(I,J,1)
  GO TO 6
572 LOK = 2
  LOT = 1
  IF(IT-24)573,53,53
573 DO 574 I=1,15
  DO 574 J=1,15
  NUM = KEY(I,J)
  DO 574 NS=1,NUM
574 TQ(I,J,NS) = Q(I,J,NS)
  GO TO 6
53 U(25) = U(24)
  DIR(25) = DIR(24)
  GO TO 10
50 CONTINUE
375 CALL EXIT
  END

```

SUBROUTINE CREA

CREA - SUBROUTINE FOR COMPUTING THE EFFECT OF AREAL SOURCE EMISSIONS UPON A RECEPTOR AT THE CENTER OF THE AREA

SUBROUTINE CREA

```

DIMENSION AREA(5,5), Q(15,15,5), U(25), KSTAB(24),
1 DIR(25), DIRVEL(2,24), KEY(15,15), BETA(15,29),
2 CHIQ(15,29,5), ZPHY(15,15,5), DY(15,29,5), IMISS(24),
3 DX(15,29,5), SN(16), X(15,29), R(15,15,5), S(15,15,5),
4 CSN(16), MU(4), MJ(50), NB(50), TQ(15,15,5), BTM(24),
5 TOP(24), CHI(15,15), NU(50), TCHI(15,15,3), CX(15,29),
6 CICQ(40,40), SIGN(15,29), HALIV(24)
COMMON ACHI, AM13, AM34, AM0, AM, AN13, AN34, AN,
1 ARFAC, A, BRG, B, BX, BY, C, DAY, DECA, DELTA, DELZ,
2 DIRANG, DIRI, DIRT, DI, DK, DL, DM, DN, D,
3 EFFZ, E, EXI, F1, F2, F3, F4, FACT, FJON, F, G, H,
4 IB, IDAY, IDIR, IHRA, IHRP, IH, II, IIS, IKE, IDIA,
5 IQUAD, I, IS, ISTAB, ISUM, ITIME, IT, IU, IYR, JIM,
6 JJ, JJS, JON, J, JS, KAPA, KAR, KAT, KEX, KMISS, KODE,
7 KONT, KUX, KOY, KT, LAMBOA, LIMN, LIM, LIN, LL, LOK,
8 L0I, LUX, L, MAN, MDIST, ML, MM, MU, MR, M, MTEMP,
9 MTHAVG, MT, MUM, NDIST, NLIM, NN, NO, N, NS, NTEMP
COMMON NT, NUMDAY, NUM, O, PLUME, P, RR, S12, S13,
1 S24, S34, SIGY, SIGZ2, SIGZI, SIGZK, SIGZ, SR, TEMPQ,
2 TEMP, THETA, TNG, T, UIM, UIN, UKM, UKN, UM1, UM2,
3 UM3, UM4, UN1, UN2, UN3, UN4, V, W, XLN, YIINT, Y1,
4 Y1S, Y2INT, Y2, Y2S, YR, Y, YY, Z2, ZH, ZOS, Z, ZZ,
5 AREA, BETA, BTM, CHIQ, CHI, CICQ, CSN, CX, DIR,
6 DIRVEL, DX, DY, IMISS, KEY, KSTAB, MJ, MU, NB, NU,
7 Q, R, SIGN, SN, S, TCHI, TOP, TQ, U, X, ZPHY, HALIV
1F(U(IT)-5.0)23,23,22
22 ARFAC = AREA(5,ISTAB)*5.0/(U(IT)*100000000.)
GO TO 37
23 IF(U(IT))24,24,40
24 GO TO (25,26,27,28,29),ISTAB
25 SIGZ = 350.0
GO TO 30
26 SIGZ = 110.0
GO TO 30
27 SIGZ = 60.0
GO TO 30
28 SIGZ = 30.0
GO TO 30
29 SIGZ = 25.0

```

```
30 Z = 2.15*SIGZ
  IF(Z-TOP(1T)*30.0)33,33,34
33 ZOS = 4.62
  GO TO 39
34 Z = TOP(1T)*30.0
  IF(SIGZ-TOP(1T)*20.0)35,36,36
35 ZUS = Z*Z/SIGZ*SIGZ
  GO TO 39
36 ZUS = 2.25
39 F = 0.8/(EXP(-ZOS/2.0)*SIGZ*2580000.)
  DO 32 I = 1,15
  DO 32 J = 1,15
  TEMPQ = 0.0
  KEX = KLY(I,J)
  DO 31 N = 1,KEX
31 TEMPQ = TEMPQ + Q(I,J,N)
32 TCHI(I,J,1) = TEMPQ*F
  GO TO 55
40 ARFAC = AREA(IU,ISTAB)/100000000.
37 DO 41 I = 1,15
  DO 41 J = 1,15
41 TCHI(I,J,1) = Q(I,J,1)*ARFAC
55 RETURN
  END
```

SUBROUTINE GARP1

GARP1 - SUBROUTINE FOR COMPUTING THE EFFECT UPON A
RECEPTOR OF EMISSIONS FROM AREAL AND POINT
SOURCES OUTSIDE THE AREA CONTAINING THE RECEPTOR

SUBROUTINE GARP1

```

DIMENSION AREA(5,5), Q(15,15,5), U(25), KSTAB(24),
1 DIR(25), DIRVEL(2,24), KEY(15,15), BETA(15,29),
2 CHIQ(15,29,5), ZPHY(15,15,5), DY(15,29,5), IMISS(24),
3 DX(15,29,5), SN(16), X(15,29), R(15,15,5), S(15,15,5),
4 CSN(16), MU(4), MJ(50), NB(50), TQ(15,15,5), BTM(24),
5 TOP(24), CHI(15,15), NU(50), TCHI(15,15,3), CX(15,29),
6 CICQ(40,40), SIGN(15,29), HALIV(24)

COMMON ACHI, AM13, AM34, AM0, AM, AN13, AN34, AN,
1 AREFAC, A, BRG, B, BX, BY, C, DAY, DECA, DELTA, DELZ,
2 DIRANG, DIRI, DIRK, DIRE, DI, DK, DL, DM, DN, D,
3 EEEZ, E, EXT, FI, F2, F3, F4, FACT, FJON, F, G, H,
4 IB, IDAY, IDIR, IHRA, IHRP, IH, II, IIS, IKE, IOTA,
5 IQUAD, I, IS, ISTAB, ISUM, ITIME, IT, IU, IYR, JIM,
6 JJ, JJS, JUN, J, JS, KAPA, KAR, KAT, KEX, KMISS, KODE,
7 KONT, KOX, KOY, KT, LAMBDA, LIMN, LIM, LIN, LL, LOK,
8 LUT, LUX, L, MAN, MDIST, ML, MM, MU, MR, M, MTEMP,
9 MTHAVG, MI, MUM, NDIST, NLIM, NN, NO, N, NS, NTEMP
COMMON AI, NUMDAY, NUM, C, PLUME, P, RR, S12, S13,
1 S24, S34, SIGY, SIGZ2, SIGZI, SIGZK, SIGZ, SR, TEMPQ,
2 TEMP, THETA, TNG, I, UIM, UIN, UKM, UKN, UMI, UM2,
3 UM3, UM4, UN1, UN2, UN3, UN4, V, W, XLN, YIINT, Y1,
4 Y1S, Y2INT, Y2, Y2S, YR, Y, YY, Z2, ZH, ZOS, Z, ZZ,
5 AREA, BETA, BTM, CHIQ, CHI, CICQ, CSN, CX, DIR,
6 DIRVEL, DX, DY, IMISS, KEY, KSTAB, MJ, MU, NB, NU,
7 Q, R, SIGN, SN, S, TCHI, TOP, TQ, U, X, ZPHY, HALIV
DO 77 N=1,15
DO 77 M= 1,29
X(N,M) = 0.0
77 BETA(N,M) = 0.0
GO TO 78,81,80,79),IDIR
78 DIRANG = 1.5708
DO 781 N = 2,15
NN = N + 14
NTEMP = N - 1
DO 781 MR = 15,NN
MM = MR - 15
AM = MM
AN = NTEMP
X(N,MR) = SQRT(AN*AN + AM*AM)*1609.0

```

```

ML = 15 - MM
SIGN(N,ML) = 1.0
SIGN(N,MR) = -1.0
X(N,ML) = X(N,MR)
BETA(N,MR) = ATANF(AM/AN)
781 BETA(N,ML) = BETA(N,MR)
GO TO 82
79 DIRANG = 1.4635
DO 791 N = 2,15
NTEMP = N - 1
ML = 15 - NTEMP/2
MR = 15 + 2*NTEMP
IF(MR = 29)793,793,792
792 MR = 29
793 DO 791 M = ML,MR
MTEMP = M - 15
AN = NTEMP
AM = MTEMP
X(N,M) = SQRTF(AN*AN + AM*AM)*1609.0
THETA = ATANF(ABSF(AM/AN))
IF(MTEMP)794,794,795
794 BETA(N,M) = THETA + .393
SIGN(N,M) = 1.0
GO TO 791
795 BETA(N,M) = THETA - 0.393
IF(BETA(N,M))796,797,797
796 BETA(N,M) = -BETA(N,M)
SIGN(N,M) = 1.0
GO TO 791
797 SIGN(N,M) = -1.0
791 CONTINUE
70 GO TO 82
80 DIRANG = 0.7854
DO 801 N=1,15
DO 801 M = 1,15
NN = N-1
AN = NN
AM = FLOATF(15-M)
X(N,M) = SQRTF(AN*AN + AM*AM)*1609.0
IF(AN)802,802,803
802 BETA(N,M) = 0.78540
SIGN(N,M) = 1.0
GO TO 801
803 THETA = ATANF(AM/AN)
BETA(N,M) = THETA-0.786
IF(BETA(N,M))804,805,805
804 BETA(N,M) = -BETA(N,M)
SIGN(N,M) = -1.0
GO TO 801
805 SIGN(N,M) = 1.0
801 CONTINUE
GO TO 82

```

```

61 CIRANG = 1.1781
DO 811 N = 2,15
NTEMP = N-1
ML = 15-Z*NTEMP
IF(ML)812,812,813
812 ML = 1
813 MR = 15 + NTEMP/2
DO 811 M = ML,MR
MTEMP = M-15
AN = NTEMP
AM = MTEMP
X(N,M) = SQRTE(AN*AN + AM*AM)*1609.0
Itheta = ATANF(ABSF(AM/AN))
IF(MTEMP)815,814,814
814 BETA(N,M) = Itheta+0.393
SIGN(N,M) = -1.0
GO TO 811
815 BETA(N,M) = Itheta-0.393
IF(BETA(N,M))816,817,817
816 BETA(N,M) = -BETA(N,M)
SIGN(N,M) = -1.0
GO TO 811
817 SIGN(N,M) = 1.0
811 CONTINUE
82 IKT = 1
821 DO 125 N=1,15
DO 125 M = 1,29
CX(N,M) = 0.0
IF(X(N,M))63,83,84
63 CHIQ(N,M,1) = 0.0
GO TO 125
84 IF(ABSF(BETA(N,M))-0.515)85,83,83
85 BX = ABSF(X(N,M)*COSF(BETA(N,M)))
851 IF(BX-U(IT)*1609.0)86,86,266
266 IF(BX-(U(IT)+U(KT))*1609.0)267,267,83
267 CX(N,M) = X(N,M)
GO TO 83
86 CY = ABSF(X(N,M)*SINF(BETA(N,M)))
GO TO (90,91,92,93,94),ISTAB
90 SIGY = 0.35*BX**0.9
901 XLN = LOGF(BX)
SIGZ = EXPF(10.81-4.07*XLN+0.495*XLN*XLN)
EXT = 1.10
GO TO 95
91 SIGY = 0.22*BX**0.9
911 XLN = LOGF(BX)
SIGZ = EXPF(3.82-1.25*XLN+0.2*XLN*XLN)
EXT = 1.16
GO TO 95
92 SIGY = 0.18*BX**0.9
921 XLN = LOGF(BX)
SIGZ = EXPF(-2.28*XLN-0.011*XLN*XLN)

```

```

EXT = 1.22
GO TO 95
93 SIGY = 0.13*BX**0.9
931 XLN = LOGF(BX)
SIGZ = EXP(-3.27+1.23*XLN-0.038*XLN*XLN)
EXT = 1.29
GO TO 95
94 SIGY = 0.1*BX**0.9
941 XLN = LOGF(BX)
SIGZ = EXP(-3.87+1.38*XLN-0.052*XLN*XLN)
EXT = 1.34
95 TEMP = 1.0
IF(SIGZ-TOP(1T)*20.0)97,97,96
96 SIGZ = TOP(1T)*20.0
97 IF(0.4*SIGZ-76.0)99,99,98
98 TEMP = (0.4*SIGZ/76.0)**EXT
99 ZH = 3.0/(U(1T)*TEMP)
EFFZ = 12.0 + 5.0*ZH*ZH*ZH
103 IF(4.3*SIGY-1609.0)104,104,105
104 IF(BY+2.15*SIGY-804.)106,106,107
107 IF(BY-2.15*SIGY-804.)105,83,83
106 FACT = 1.0
GO TO 109
105 Y1 = (BY-804.0)/SIGY
Y2 = (BY+804.0)/SIGY
Y1S = Y1*Y1
F1 = (945.+105.*Y1S+8.*Y1S*Y1S)*ABSF(Y1)
F2 = 945.-210.*Y1S+15.*Y1S*Y1S
Y1INT = EXP(-Y1S/2.0)/2.5*F1/F2
Y2S = Y2*Y2
F3 = (945.+105.*Y2S+8.*Y2S*Y2S)*ABSF(Y2)
F4 = 945.-210.*Y2S+15.*Y2S*Y2S
Y2INT = EXP(-Y2S/2.0)/2.5*F3/F4
Y1INT = Y1INT*ABSF(Y1)/Y1
Y2INT = Y2INT*ABSF(Y2)/Y2
FACT = ABSF(Y1INT-Y2INT)
109 SIGZ2 = SIGZ*SIGZ
Z2 = EFFZ*EFFZ
DK = EXP(-0.693*BX/(HALIV(1T)*U(1T)*1609.*TEMP))
100 CHIQ(N,M,U)=FACT/(U(1T)*TEMP*4536000.*SIGZ*
                           EXP(Z2/2.*SIGZ2)))*DK
DX(N,M,1) = BX
DY(N,M,1) = BY
125 CONTINUE
275 DO 150 I=1,15
DO 150 J=1,15
DO 111 N=1,15
II = N+I-1
IF(II-15)112,112,150
112 DO 110 M=1,29
IF(CHK(N,M,1))110,110,113
113 JJ=J-15+M

```

```

1F(JJ)110,110,114
114 IF(JJ-15)115,115,111
115 GO TO (116,117,118,119),IQUAD
116 IS = I
  JS = J
  IIS = II
  JJS = JJ
  GO TO 120
117 IS = J
  JS = 16-I
  IIS = JJ
  JJS = 16-II
  GO TO 120
118 IS = 16-I
  JS = 16-J
  IIS = 16-II
  JJS = 16-JJ
  GO TO 120
119 IS = 16-J
  JS = I
  IIS = 16-JJ
  JJS = II
120 IF(KEY(IS,JS)-1)126,126,121
126 NUM = 1
  GO TO 152
121 NUM = KEY(IS,JS)
124 DO 140 NS = 2,NUM
  IF(ZPHY(IS,JS,NS) -BTM(IT)*25.)102,133,133
102 GO TO (127,128,129,130),IQUAD
127 W = R(IS,JS,NS)
  Y = S(IS,JS,NS)
  GO TO 131
128 W = -S(IS,JS,NS)
  Y = R(IS,JS,NS)
  GO TO 131
129 W = -R(IS,JS,NS)
  Y = -S(IS,JS,NS)
  GO TO 131
130 W = S(IS,JS,NS)
  Y = -R(IS,JS,NS)
131 W = W*COSF(DIRANG) + Y*SINF(DIRANG)
  Y = Y*COSF(DIRANG) - W*SINF(DIRANG)
  IF(DX(N,M,1))133,133,132
133 CHIQIN,M,NS) = 0.0
  GO TO 140
132 DX(N,M,NS) = DX(N,M,1) + W
  DY(N,M,NS) = ABSF(DY(N,M,1)*SIGN(N,M)-Y)
  GO TO (135,136,137,138,139),ISTAB
135 SIGY = 0.35*DX(N,M,NS)**0.9
  PLUME = 1.25
  EXT = 1.10
  XLN = LOGF(DX(N,M,NS))

```

```

SIGZ = EXPF(10.8I-4.07*XLN+0.495*XLN*XLN)
GO TO 141
136 SIGY = 0.22*DX(N,M,NS)**0.9
PLUME = 1.16
EXT = 1.16
XLN = LOGF(DX(N,M,NS))
SIGZ = EXPF(3.82-1.25*XLN+0.2*XLN*XLN)
GO TO 141
137 SIGY = 0.18*DX(N,M,NS)**0.9
PLUME = 1.08
EXT = 1.22
XLN = LOGF(DX(N,M,NS))
SIGZ = EXPF(-2.28+XLN-0.011*XLN*XLN)
GO TO 141
138 SIGY = 0.13*DX(N,M,NS)**0.9
PLUME = 1.00
EXT = 1.29
XLN = LOGF(DX(N,M,NS))
SIGZ = EXPF(-3.27+1.23*XLN-0.038*XLN*XLN)
GO TO 141
139 SIGY = 0.1*DX(N,M,NS)**0.9
PLUME = 0.90
EXT = 1.34
XLN = LOGF(DX(N,M,NS))
SIGZ = EXPF(-3.87+1.38*XLN-0.052*XLN*XLN)
141 TEMP = 1.0
IF(2.15*SIGY-DY(N,M,NS))142,143,143
142 CHIQ(N,M,NS) = 0.0
GO TO 140
143 IF(SIGZ-TOP(IT)*20.0)145,145,144
144 SIGZ = TOP(IT)*20.0
145 IF(0.4*SIGZ-55.0)147,147,146
146 TEMP = (0.4*SIGZ/76.0)**EXT
147 DELZ = (2.4*PLUME/(U(IT)*TEMP))*DX(N,M,NS)**0.66
149 EFFZ = DELZ + ZPHY(IS,JS,NS)
IF(EFFZ-30.0*TOP(IT))151,151,947
947 EFFZ = 30.0*TOP(IT)
151 YY = DY(N,M,NS)*DY(N,M,NS)/(-2.*SIGY*SIGY)
ZZ = EFFZ*EFFZ/(-2.*SIGZ*SIGZ)
DK=EXP(-0.693*DX(N,M,NS)/(HALIV(IT)*U(IT)*1609.*TEMP))
CHIQ(N,M,NS)=EXP(YY+ZZ)*DK/(5050.*U(IT)*SIGY*SIGZ*TEMP)
140 CONTINUE
152 DO 955 NS=1,NUM
955 TCHI(IIS,JJS,1)=CHIQ(N,M,NS)*Q(IS,JS,NS)+TCHI(IIS,JJS,1)
110 CONTINUE
111 CONTINUE
150 CONTINUE
RETURN
END

```

SUBROUTINE PTIN

PTIN - SUBROUTINE FOR COMPUTING THE EFFECT FROM POINT SOURCE EMISSIONS FROM POINTS WITHIN THE AREA OF THE RECEPTOR

SUBROUTINE PTIN

```

DIMENSION AREA(5,5), Q(15,15,5), U(25), KSTAB(24),
1 DIR(25), DIRVEL(2,24), KEY(15,15), BETA(15,29),
2 CHIQ(15,29,5), ZPHY(15,15,5), DY(15,29,5), IMISS(24),
3 DX(15,29,5), SN(16), X(15,29), R(15,15,5), S(15,15,5),
4 CSN(16), MU(4), MJ(50), NB(50), TQ(15,15,5), BTM(24),
5 TOP(24), CHI(15,15), NU(50), TCHI(15,15,3), CX(15,29),
6 CICQ(40,40), SIGN(15,29), HALIV(24)
COMMON ACHI, AM13, AM34, AM0, AM, AN13, AN34, AN,
1 ARFAC, A, BRG, B, BX, BY, C, DAY, DECA, DELTA, DELZ,
2 DIRANG, DIRI, DIRK, DIRT, DI, DK, DL, DM, DN, D,
3 EFFZ, E, EKT, F1, F2, F3, F4, FACT, FJON, F, G, H,
4 IB, IDAY, ICIR, IHRA, IHRP, IH, II, IIS, IKE, ICTA,
5 IQUAD, I, IS, ISTAB, ISUM, ITIME, IT, IU, IYR, JIM,
6 JJ, JJS, JCN, J, JS, KAPA, KAR, KAT, KEX, KMISS, KODE,
7 KCNT, KUX, KCY, KT, LAMBDA, LIMN, LIM, LIN, LL, LOK,
8 LOT, LUX, L, MAN, MDIST, ML, MM, MU, MR, M, MTEMP,
9 MTHAVG, MI, MUM, MDIST, NLIM, NN, NO, N, NS, NTEMP
COMMON NT, NUMDAY, NUM, O, PLUME, P, RR, S12, S13,
1 S24, S34, SIGY, SIGZ2, SIGZI, SIGZK, SIGZ, SR, TEMPQ,
2 TEMP, THETA, TNG, T, UIM, UIN, UKM, UKN, UMI, UM2,
3 UM3, UM4, UN1, UN2, UN3, UN4, V, W, XLN, Y1INT, Y1,
4 Y1S, Y2INT, Y2, Y2S, YR, Y, YY, Z2, ZH, ZOS, Z, ZZ,
5 AREA, BETA, BTM, CHIQ, CHI, CICQ, CSN, CX, DIR,
6 DIRVEL, DX, DY, IMISS, KEY, KSTAB, MJ, MU, NB, NU,
7 Q, R, SIGN, SN, S, TCHI, TOP, TQ, U, X, ZPHY, HALIV
160 DO 175 I=1,15
    DO 175 J=1,15
        ACHI = 0.0
        NUM = KEY(I,J)
        IF(NUM-1)175,175,161
161 DO 174 NS=2,NUM
        IF(ZPHY(I,J,NS)-25.0*BTM(IT))660,174,174
660 GO TO (127,128,129,130),IQUAD
127 W = R(I,J,NS)
    Y = S(I,J,NS)
    GO TO 661
128 W = -S(I,J,NS)
    Y = R(I,J,NS)
    GO TO 661

```

```

129 W = -R(I,J,NS)
      Y = -S(I,J,NS)
      GO TO 661
130 W = S(I,J,NS)
      Y = -R(I,J,NS)
661 W = W*COSF(DIRANG) + Y*SINF(DIRANG)
      Y = Y*COSF(DIRANG) - W*SINF(DIRANG)
      IF(W)174,174,662
662 GO TO(162,163,164,165,166),ISTAB
162 SIGY = 0.35*W**0.9
      PLUME = 1.25
      XLN = LOGF(W)
      SIGZ = EXPF(10.81-4.07*XLN+0.495*XLN*XLN)
      GO TO 167
163 SIGY = 0.22*W**0.9
      PLUME = 1.16
      XLN = LOGF(W)
      SIGZ = EXPF(3.82-1.25*XLN+0.200*XLN*XLN)
      GO TO 167
164 SIGY = 0.18*W**0.9
      PLUME = 1.08
      XLN = LOGF(W)
      SIGZ = EXPF(-2.28+1.00*XLN-0.011*XLN*XLN)
      GO TO 167
165 SIGY = 0.13*W**0.9
      PLUME = 1.00
      XLN = LOGF(W)
      SIGZ=EXPF(-3.27+1.23*XLN-0.038*XLN*XLN)
      GO TO 167
166 SIGY = 0.10*w**0.9
      PLUME = 0.90
      XLN = LOGF(W)
      SIGZ = EXPF(-3.87+1.38*XLN-0.052*XLN*XLN)
167 IF(2.15*SIGY - Y)174,168,168
168 IF(SIGZ-20.0*TOP(IT))170,170,169
169 SIGZ=20.0*TOP(IT)
170 DELZ = 2.4*PLUME/U(IT)*W**0.66
172 EFFZ = DELZ + ZPHY(I,J,NS)
      IF(EFFZ-30.0*TOP(IT))173,173,973
973 EFFZ = 30.0*IUP(IT)
173 YY = -Y*Y/(2.*SIGY*SIGY)
      ZZ=-EFFZ*EFFZ/(2.*SIGZ*SIGZ)
      DK = EXPF(-0.693*W/(U(IT)*1609.*HALIV(IT)))
      ACHI=DK*EXPF(YY+ZZ)/(5050.*U(IT)*ISGY*SIGZ)*Q(I,J,NS)
                           + ACHI
174 CONTINUE
      ICHI(I,J,1) = TCHI(I,J,1) + ACHI
175 CONTINUE
      RETURN
      END

```

SUBROUTINE DRIFTA

DRIFTA - SUBROUTINE FOR COMPUTING THE EFFECT OF A DRIFTING PLUME WHEN THERE HAS BEEN A CHANGE IN WIND DIRECTION

SUBROUTINE DRIFTA

```

DIMENSION AREA(5,5), G(15,15,5), U(25), KSTAB(24),
1 DIR(25), DIRVEL(2,24), KEY(15,15), BETA(15,29),
2 CHIQ(15,29,5), ZPHY(15,15,5), DY(15,29,5), IMISS(24),
3 DX(15,29,5), SN(16), X(15,29), R(15,15,5), S(15,15,5),
4 CSN(16), MU(4), MJ(50), NB(50), TQ(15,15,5), BTM(24),
5 TOP(24), CHI(15,15), NU(50), TCHI(15,15,3), CX(15,29),
6 CICQ(40,40), SIGN(15,29), HALIV(24)
COMMON ACHI, AM13, AM34, AM0, AM, AN13, AN34, AN,
1 ARFAC, A, BRG, B, BX, BY, C, DAY, DECA, DELTA, DELZ,
2 DIRANG, DIRI, DIRK, DIRE, DI, DK, DL, DM, DN, D,
3 EFFZ, E, EXT, F1, F2, F3, F4, FACT, FJON, F, G, H,
4 IB, IDAY, IDIR, IHRA, IHRP, IH, II, IIS, IKE, IOTA,
5 IQUAD, I, IS, ISTAB, ISUM, ITIME, IT, IU, IYR, JIM,
6 JJ, JJS, JON, J, JS, KAPA, KAR, KAT, KEX, KMISS, KODE,
7 KONT, KOX, KOY, KT, LAMBDA, LIMN, LIM, LIN, LL, LOK,
8 LOT, LUX, L, MAN, MDIST, ML, MM, MU, MR, M, MTEMP,
9 MTHAVG, MT, MUM, NDIST, NLIM, NN, NO, N, NS, NTEMP
COMMON NT, NUMDAY, NUM, C, PLUME, P, RR, S12, S13,
1 S24, S34, SIGY, SIGZ2, SIGZI, SIGZK, SIGZ, SR, TEMPQ,
2 TEMP, THETA, TNG, T, UIM, UIN, UKM, UKN, UM1, UM2,
3 UM3, UM4, UN1, UN2, UN3, UN4, V, W, XLN, Y1INT, Y1,
4 Y1S, Y2INT, Y2, Y2S, YR, Y, YY, Z2, ZH, ZOS, Z, ZZ,
5 AREA, BETA, BTM, CHIQ, CHI, CICQ, CSN, CX, DIR,
6 DIRVEL, DX, DY, IMISS, KEY, KSTAB, MJ, MU, NB, NU,
7 Q, R, SIGN, SN, S, TCHI, TOP, TQ, U, X, ZPHY, HALIV
NU(3) = NU(1) + NU(2)
MU(3) = MU(1) + MU(2)
NU(4) = 0
MU(4) = 0
DO 196 I=1,3
JJ = I+1
DO 196 J=JJ,4
1F(MU(I)-MU(J))196,196,195
195 NTEMP = MU(I)
MU(I) = MU(J)
MU(J) = NTEMP
NTEMP = NU(I)
NU(I) = NU(J)
NU(J) = NTEMP

```

```

196 CONTINUE
  UN1 = NU(1)
  UN2 = NU(2)
  UN3 = NU(3)
  UN4 = NU(4)
  UM1 = MU(1)
  UM2 = MU(2)
  UM3 = MU(3)
  UM4 = MU(4)
  L = MU(4) - MU(1)
  L = MU(4)-MU(1)+1
  IF(UM4-UM3)197,197,327
197 IF(UN4-UN3)223,224,224
223 NTEMP = NU(3)
  NU(3) = NU(4)
  NU(4) = NTEMP
224 IF(UN2-UN1)325,326,326
325 NTEMP = NU(2)
  NU(2) = NU(1)
  NU(1) = NTEMP
326 UN1 = NU(1)
  UN2 = NU(2)
  UN3 = NU(3)
  UN4 = NU(4)
327 AN13 = UN3-UN1
  AM13 = UM3-UM1
  IF(AM13)199,198,199
198 S13 = 100.*ABSF(AN13)/AN13
  GO TO 200
199 S13 = AN13/AM13
200 AN34 = UN4-UN3
  AM34 = UM4-UM3
  IF(AM34)201,400,201
400 S34 = 100.*ABSF(AN34)/AN34
  GO TO 202
201 S34 = AN34/AM34
202 S12 = S34
207 S24 = S13
  KOY = 1
  KOX = 1
  DO 225 M=1,L
  MT = M-1
  NUM = MU(1)+MT
  GO TO (211,215),KOY
211 F = MT
  IF(ABSF(S13)-95.0)213,213,212
212 H = UN3
  KOY = 2
  GO TO 216
213 H = F*S13+UN1
  IF(MU(3)-MUM)214,216,216
214 KOY = 2

```

```

215 F = FLOAT(MUM-MU(3))
      H = F*S34+UN3
216 GO TO (217,221),K0X
217 F = M1
      IF(ABSF(S12)-95.0)219,219,218
218 B = UN2
      K0X = 2
      GO TO 222
219 B = F*S12+UN1
      IF(MU(2)-MUM)220,222,222
220 K0X = 2
221 F = FLOAT(MUM-MU(2))
      B = F*S24+UN2
222 IH = B
      IB = H
      IF(IH-IB)209,210,210
209 NTEMP = IH
      IH = IB
      IB = NTEMP
210 LIMN = IH-IB+1
      MDIST = MU(1)+M-1
      DM = MDIST
      DO 225 N=1,LIMN
      CICQ(M,N) = 0.0
      NDIST = IB+N-1
      DN = NDIST
      DK = ABSF((DM*SN(IOTA)+DN*CSN(IOTA))/SN(KAPA))
      DI = ABSF(DM*CSN(IOTA)-DN*SN(IOTA)-DK*CSN(KAPA))
      IF(DK)228,228,226
226 DL = LOGF(DK*1609.0)
      SIGZK = EXPF(A+C*DL+D*DL*DL)
      EFFZ = 25. + 320./(U(IT)+U(KT))**3.
      TEMP = 1. / (2020.*U(KT)*EXPF(EFFZ*EFFZ/(2.*SIGZK*SIGZK)))
      IF(DI)228,228,227
227 DL = LOGF((DK+DI)*1609.0)
      SIGZI = EXPF(A+C*DL+D*DL*DL)
      DECA = EXPF(-0.693*(1.0+DI/U(IT))/HALIV(IT))
      CICQ(M,N) = TEMP*DECA/(SIGZI*SN(KAPA)*U(IT)*1609.)
228 NB(M) = IB
      NU(M) = IH
225 CONTINUE
      DO 236 I=1,15
      DO 236 J=1,15
      TEMPQ = 0.0
      DO 235 NS=1,5
235 TEMPQ = TEMPQ+TQ(I,J,NS)
      DO 236 M=1,L
      MT = M-1
      JJ = J+MU(1)+MT
      IF(JJ)236,236,233
233 IF(JJ-15)237,237,236
237 NLIM = NU(M)-NB(M)+1

```

```
LO 271 N=I,NLIM
NT = N-1
II = NB(M)+NI+1
IF(II)271,271,234
234 IF(II-15)238,238,271
238 TCHI(II,JJ,1) = CICQ(M,N)*TEMPQ+TCHI(II,JJ,1)
271 CONTINUE
236 CONTINUE
      RETURN
      END
```

SUBROUTINE DRIFTB

DRIFTB - SUBROUTINE FOR COMPUTING THE EFFECT OF A DRIFTING PLUME WHEN A CALM PERSISTS DURING THE CURRENT HOUR

SUBROUTINE DRIFTB

```

DIMENSION AREA(5,5), Q(15,15,5), U(25), KSTAB(24),
1 DIR(25), DIRVEL(2,24), KEY(15,15), BETA(15,29),
2 CHIQ(15,29,5), ZPHY(15,15,5), DY(15,29,5), IMISS(24),
3 DX(15,29,5), SN(16), X(15,29), R(15,15,5), S(15,15,5),
4 CSN(16), MU(4), MJ(50), NB(50), TQ(15,15,5), BTM(24),
5 TOP(24), CHI(15,15), NU(50), TCHI(15,15,3), CX(15,29),
6 CICQ(40,40), SIGN(15,29), HALIV(24)
COMMON ACHI, AM13, AM34, AMO, AM, AN13, AN34, AN,
1 ARFAC, A, BRG, B, BX, BY, C, DAY, DECA, DELTA, DELZ,
2 DIRANG, DIRI, DIRK, DIRT, DI, DK, DL, DM, DN, D,
3 EFFZ, E, EXT, F1, F2, F3, F4, FACT, FJON, F, G, H,
4 IB, IDAY, IDIR, IHRA, IHRP, IH, II, IIS, IKE, IOTA,
5 IQUAD, I, IS, ISTAB, ISUM, ITIME, IT, IU, IYR, JIM,
6 JJ, JJS, JCN, J, JS, KAPA, KAR, KAT, KEX, KMISS, KODE,
7 KONT, KEX, KUY, KT, LAMBDA, LIMN, LIM, LIN, LL, LOK,
8 LOT, LOX, L, MAN, MDIST, ML, MM, MO, MR, M, MTEMP,
9 MTHAVG, MT, MUM, NDIST, NLIM, NN, NO, N, NS, NTEMP
COMMON NT, NUMDAY, NUM, C, PLUME, P, RR, S12, S13,
1 S24, S34, SIGY, SIGZ2, SIGZI, SIGZK, SIGZ, SR, TEMPQ,
2 TEMP, THETA, TNG, T, UIM, UIN, UKM, UKN, UMI, UM2,
3 UM3, UM4, UN1, UN2, UN3, UN4, V, W, XLN, Y1INT, Y1,
4 Y1S, Y2INT, Y2, Y2S, YR, Y, YY, Z2, ZH, ZOS, Z, ZZ,
5 AREA, BETA, BTM, CHIQ, CHI, CICQ, CSN, CX, DIR,
6 DIRVEL, DX, DY, IMISS, KEY, KSTAB, MJ, MU, NB, NU,
7 Q, R, SIGN, SN, S, TCHI, TOP, TQ, U, X, ZPHY, HALIV
DO 241 I=1,15
DO 241 J=1,15
241 TCHI(I,J,1)=TCHI(I,J,2)*E*EXP(-0.693/HALIV(IT))
               +TCHI(I,J,1)
RETURN
END

```

SUBROUTINE DRIFTC

DRIFTC - SUBROUTINE FOR COMPUTING THE EFFECT OF A DRIFTING PLUME WHEN A CALM EXISTED THE PREVIOUS HOUR

SUBROUTINE DRIFTC

```

DIMENSION AREA(5,5), Q(15,15,5), U(25), KSTAB(24),
1 DIR(25), DIRVEL(2,24), KEY(15,15), BETA(15,29),
2 CHIC(15,29,5), ZPHY(15,15,5), DY(15,29,5), IMISS(24),
3 DX(15,29,5), SN(16), X(15,29), R(15,15,5), S(15,15,5),
4 CSN(16), MU(4), MJ(50), NB(50), TQ(15,15,5), BTM(24),
5 TOP(24), CHI(15,15), NU(50), TCH1(15,15,3), CX(15,29),
6 CICQ(40,40), SIGN(15,29), HALIV(24)

COMMON ACH1, AM13, AM34, AM0, AM, AN13, AN34, AN,
1 ARFAC, A, BRG, B, BX, BY, C, DAY, DECA, DELTA, DELZ,
2 DIRANG, DIR1, DIRK, DIRT, DI, DK, DL, DM, DN, D,
3 EFFZ, E, EXIT, F1, F2, F3, F4, FACT, FJON, F, G, H,
4 IB, IDAY, IDIR, IHRA, IHRP, IH, II, IIS, IKA, IOTA,
5 IQUAD, I, IS, ISTAB, ISUM, ITIME, IT, IU, IYR, JIM,
6 JJ, JJS, JKA, J, JS, KAPA, KAR, KAT, KEX, KMISS, KODE,
7 KUNI, KUX, KUY, KT, LAMBDA, LIMN, LIM, LIN, LL, LCK,
8 LUF, LCK, L, MAN, MDIST, ME, MM, MU, MR, M, MTEMP,
9 MTHAVG, MT, NUM, NODIST, NLIM, NN, NO, N, NS, NTEMP

COMMON NF, NUMDAY, NUM, O, PLUME, P, RR, S12, S13,
1 S24, S34, SIGY, SIGZ2, SIGZI, SIGZK, SIGZ, SR, TEMPQ,
2 TEMP, THETA, TNG, I, UIM, UIN, UKM, UKN, UMI, UM2,
3 UMB, UM4, UN1, UN2, UN3, UN4, V, W, XLN, YIINT, YI,
4 YIS, YZINT, Y2, Y2S, YR, Y, YY, Z2, ZH, ZOS, Z, ZZ,
5 AREA, BETA, BTM, CHIC, CHI, CICQ, CSN, CX, DIR,
6 DIRVEL, DX, DY, IMISS, KEY, KSTAB, MJ, MU, NB, NU,
7 Q, R, SIGN, SN, S, TCH1, TOP, TQ, U, X, ZPHY, HALIV
8 BRG = DIR(II)-9.0
9 IOTA = IKA
10 IF(IOTA)251,251,252
251 IOTA = IOTA+16
252 U = ABSF(U(IT)*SN(IOTA))
11 P = ABSF(U(IT)*CSN(IOTA))
12 IF(IOTA-4)257,254,257
257 IF(IOTA-12)253,254,253
253 TNG = ABSF(SN(IOTA)/CSN(IOTA))
13 NU = U
14 V = ABSF(SN(IOTA))/SN(IOTA)
15 W = ABSF(CSN(IOTA))/CSN(IOTA)
16 DO 255 M=1,NL
17 U = FLOAT(M)*W

```

```

P = FLOATF(M)*TNG*V
MJ(M) = 0
NU(M) = P
I = LOGF(0/CSN(IOTA)*1609.0+1000.)
SIGZ = EXPF(A+C*T+D*T*T)
DK = EXPF(-0.693/HALIV(IT))
255 CICQ(M,I) = G/(SIGZ*U(IT)*1609.)*DK
GO TO 259
254 NU = 0
V = ABSF(SN(IOTA))/SN(IOTA)
DO 256 M=1,NU
C = FLOATF(M)*W
MJ(M) = 0
NU(M) = 0
I = LOGF(0*1609.+1000.)
SIGZ = EXPF(A+C*T+D*T*T)
DK = EXPF(-0.693/HALIV(IT))
256 CICQ(M,I) = G/(SIGZ*U(IT)*1609.)*DK
259 DO 262 I=1,15
DO 262 J=1,15
DO 262 M=1,NC
II = I+NU(M)
IF(II)262,262,260
260 IF(II-16)263,262,262
263 JJ = J+MJ(M)
IF(JJ)262,262,261
261 IF(JJ-16)264,262,262
264 TCHI(II,JJ,1) = TCHI(II,JJ,1) + TCHI(I,J,2)*CICQ(M,1)
262 CONTINUE
RETURN
END

```

SUBROUTINE DRIFTD

DRIFTD - SUBROUTINE FOR COMPUTING THE EFFECT OF A DRIFTING PLUME WHEN THERE IS NO CHANGE IN WIND DIRECTION

SUBROUTINE DRIFTD

```

DIMENSION AREA(5,5), Q(15,15,5), U(25), KSTAB(24),
1 DIR(25), DIRVEL(2,24), KEY(15,15), BETA(15,29),
2 CHIQ(15,29,5), ZPHY(15,15,5), DY(15,29,5), IMISS(24),
3 DX(15,29,5), SN(16), X(15,29), R(15,15,5), S(15,15,5),
4 CSN(16), MU(4), MJ(50), NB(50), TQ(15,15,5), BTM(24),
5 TOP(24), CHI(15,15), NU(50), TCHI(15,15,3), CX(15,29),
6 CICQ(40,40), SIGN(15,29), HALIV(24)
COMMON ACHI, AM13, AM34, AMO, AM, AN13, AN34, AN,
1 ARFAC, A, BRG, B, BX, BY, C, DAY, DECA, DELTA, DELZ,
2 DIRANG, DIRI, DIRK, DIRT, DI, DK, DL, DM, DN, D,
3 EFFZ, E, EXT, F1, F2, F3, F4, FACT, FJUN, F, G, H,
4 IB, IDAY, IDIR, IHRA, IHRP, IH, II, IIS, IKE, IOTA,
5 IQUAD, I, IS, ISTAB, ISUM, ITIME, IT, IU, IYR, JIM,
6 JJ, JJS, JON, J, JS, KAPA, KAR, KAT, KEX, KMISS, KODE,
7 KONT, KOX, KOY, KT, LAMBDA, LIMN, LIM, LIN, LL, LOK,
8 LOT, LLX, L, MAN, MDIST, ML, MM, MO, MR, M, MTEMP,
9 MTHAVG, MT, MUM, NDIST, NLIM, NN, NO, N, NS, NTEMP
COMMON NT, NUMDAY, NUM, O, PLUME, P, RR, S12, S13,
1 S24, S34, SIGY, SIGZ2, SIGZI, SIGZK, SIGZ, SR, TEMPQ,
2 TEMP, THETA, TNG, T, UIM, UIN, UKM, UKN, UM1, UM2,
3 UM3, UM4, UN1, UN2, UN3, UN4, V, W, XLN, YIINT, YI,
4 Y1S, Y2INT, Y2, Y2S, YR, Y, YY, Z2, ZH, ZOS, Z, ZZ,
5 AREA, BETA, BTM, CHIQ, CHI, CICQ, CSN, CX, DIR,
6 DIRVEL, DX, DY, IMISS, KEY, KSTAB, MJ, MU, NB, NU,
7 Q, R, SIGN, SN, S, TCHI, TOP, TQ, U, X, ZPHY, HALIV
DO 410 N=1,15
DO 410 M=1,29
410 X(N,M) = CX(N,M)
      KAT = 2
      IKE = 2
      IT = IT-ITIME
      DO 436 N=1,15
      DO 436 M = 1,29
      CX(N,M) = 0.0
      BX = ABSF(X(N,M)*COSF(BETA(N,M)))
417  DY = ABSF(X(N,M)*SINF(BETA(N,M)))
      GO TO(418,420,422,424,426),ISTAB
418  SIGY = 0.35*BX**0.9
419  XLN = LOGF(BX)

```

```

SIGZ = EXPF(10.81-4.07*XLN+0.495*XLN*XLN)
EXT = 1.10
GO TO 428
420 SIGY = 0.22*BX**0.9
421 XLN = LOGF(BX)
SIGZ = EXPF(3.82-1.25*XLN+0.2*XLN*XLN)
EXT = 1.16
GO TO 428
422 SIGY = 0.18*BX**0.9
423 XLN = LOGF(BX)
SIGZ = EXPF(-2.28+XLN-0.011*XLN*XLN)
EXT = 1.22
GO TO 428
424 SIGY = 0.13*BX**0.9
425 XLN = LOGF(BX)
SIGZ = EXPF(-3.27+1.23*XLN-0.038*XLN*XLN)
EXT = 1.29
GO TO 428
426 SIGY = 0.1*BX**0.9
427 XLN = LOGF(BX)
SIGZ = EXPF(-3.87+1.38*XLN-0.052*XLN*XLN)
EXT = 1.34
428 TEMP = 1.0
IF(SIGZ-TOP(IT)*20.0)430,430,429
429 SIGZ = TOP(IT)*20.0
430 IF(0.4*SIGZ-76.0)432,432,431
431 TEMP = (0.4*SIGZ/76.0)**EXT
432 ZH = 3.0/(U(IT)*TEMP)
EFFZ = 12.0 + 5.0*ZH*ZH*ZH
IF(4.3*SIGY-1609.0)433,433,434
433 IF(BY+2.15*SIGY-804.)411,411,412
411 FACT = 1.0
GO TO 435
412 IF(BY-2.15*SIGY-804.)434,409,409
409 CHIQ(N,M,1) = 0.0
GO TO 436
434 Y1 = (BY-804.0)/SIGY
Y2 = (BY+804.0)/SIGY
Y1S = Y1*Y1
F1 = (945.+105.*Y1S+8.*Y1S*Y1S)*ABSF(Y1)
F2 = 945.-210.*Y1S+15.*Y1S*Y1S
Y1INT = EXPF(-Y1S/2.0)/2.5*F1/F2
Y2S = Y2*Y2
F3 = (945.+105.*Y2S+8.*Y2S*Y2S)*ABSF(Y2)
F4 = 945.-210.*Y2S+15.*Y2S*Y2S
Y2INT = EXPF(-Y2S/2.0)/2.5*F3/F4
Y1INT = Y1INT*ABSF(Y1)/Y1
Y2INT = Y2INT*ABSF(Y2)/Y2
FACT = ABSF(Y1INT-Y2INT)
435 SIGZ2 = SIGZ*SIGZ
Z2 = EFFZ*EFFZ
OK = EXPF(-0.693*BX/(HALIV(IT)*U(IT)*1609.*TEMP))

```

```

CHIQ(N,M,U)=FACT/(U(IT)*TEMP*4536000.*SIGZ*
                           EXPF(ZZ/2.*SIGZ2)))*DK
DX(N,M,I) = BX
DY(N,M,I) = BY
436 CONTINUE
DO 477 I=1,15
DO 477 J=1,15
DO 476 N=1,15
II = N+I-1
IF(II-15)437,437,477
437 DO 475 M=1,29
IF(CHK(N,M,1))475,475,438
438 JJ=J-15+M
IF(JJ)475,475,439
439 IF(JJ-15)440,440,476
440 GO TO (441,442,443,444),IQUAD
441 IS = I
JS = J
IIS = II
JJS = JJ
GO TO 445
442 IS = J
JS = 16-I
IIS = JJ
JJS = 16-II
GO TO 445
443 IS = 16-I
JS = 16-J
IIS = 16-II
JJS = 16-JJ
GO TO 445
444 IS = 16-J
JS = I
IIS = 16-JJ
JJS = II
445 IF(KEY(IIS,JS)-1)446,446,447
446 NUM = 1
GO TO 478
447 NUM = KEY(IS,JS)
450 DO 473 NS = 2,NUM
IF(ZPHY(IS,JS,NS) -BTM(IT)*25.)451,451,457
451 GO TO (452,453,454,455),IQUAD
452 W = R(IS,JS,NS)
Y = S(IS,JS,NS)
GO TO 456
453 W = -S(IS,JS,NS)
Y = R(IS,JS,NS)
GO TO 456
454 W = -R(IS,JS,NS)
Y = -S(IS,JS,NS)
GO TO 456
455 W = S(IS,JS,NS)

```

```

Y = -R(IS,JS,NS)
456 W = W*COSF(DIRANG) + Y*SINF(DIRANG)
Y = Y*COSF(DIRANG) - W*SINF(DIRANG)
IF(DX(N,M,1))457,457,458
457 CHIQ(N,M,NS) = 0.0
GO TO 473
458 DX(N,M,NS) = DX(N,M,1) + W
DY(N,M,NS) = ABSF(DY(N,M,1)*SIGN(N,M)-Y)
GO TO (459,460,461,462,463),ISTAB
459 SIGY = 0.35*DX(N,M,NS)**0.9
PLUME = 1.25
EXT = 1.10
XLN = LOGF(DX(N,M,NS))
SIGZ = EXPF(10.81-4.07*XLN+0.495*XLN*XLN)
GO TO 464
460 SIGY = 0.22*DX(N,M,NS)**0.9
PLUME = 1.16
EXT = 1.16
XLN = LOGF(DX(N,M,NS))
SIGZ = EXPF(3.82-1.25*XLN+0.2*XLN*XLN)
GO TO 464
461 SIGY = 0.18*DX(N,M,NS)**0.9
PLUME = 1.08
EXT = 1.22
XLN = LOGF(DX(N,M,NS))
SIGZ = EXPF(-2.28+XLN-0.011*XLN*XLN)
GO TO 464
462 SIGY = 0.13*DX(N,M,NS)**0.9
PLUME = 1.00
EXT = 1.29
XLN = LOGF(DX(N,M,NS))
SIGZ = EXPF(-3.27+1.23*XLN-0.038*XLN*XLN)
GO TO 464
463 SIGY = 0.1*DX(N,M,NS)**0.9
PLUME = 0.90
EXT = 1.34
XLN = LOGF(DX(N,M,NS))
SIGZ = EXPF(-3.87+1.38*XLN-0.052*XLN*XLN)
464 TEMP = 1.0
IF(2.15*SIGY-DY(N,M,NS))465,466,466
465 CHIQ(N,M,NS) = 0.0
GO TO 473
466 IF(SIGZ-TOP(IT)*20.0)468,468,467
467 SIGZ = TOP(IT)*20.0
468 IF(0.4*SIGZ-55.0)470,470,469
469 TEMP = (0.4*SIGZ-76.0)**EXT
470 DELZ = (2.4*PLUME/(U(IT)*TEMP))*DX(N,M,NS)**0.66
EFFZ = DELZ + ZPHY(IS,JS,NS)
IF(EFFZ-30.0*TOP(IT))472,472,471
471 EFFZ = 30.0*TOP(IT)
472 YY = DY(N,M,NS)*DY(N,M,NS)/(-2.*SIGY*SIGY)
ZZ = EFFZ*EFFZ/(-2.*SIGZ*SIGZ)

```

```
DK=EXP(-0.693*DX(N,M,NS)/(HALIV(IT)*U(IT)*1609.*TEMP))
CHIQ(N,M,NS)=EXP(YY+ZZ)*DK/(5050.*U(IT)*SIGY*SIGZ*TEMP)
473 CONTINUE
478 DO 474 NS=1,NUM
474 TCHI(IIS,JJS,1) = CHIQ(N,M,NS)*TQ(IS,JS,NS)+TCHI(IIS,JJS,1)
475 CONTINUE
476 CONTINUE
477 CONTINUE
IT = IT+ITIME
RETURN
END
```

APPENDIX 2

PROGRAM FOR CALCULATING SULFUR DIOXIDE EMISSIONS
FROM DWELLINGS AND POWER GENERATING PLANTS

```
DIMENSION W(15,15,3), S(15,15,3), HEAT(15,15),
1 TEMP(24,31), DWEL(15,15), ROOM(15,15), EMISS(15,15,3),
2 DWL(225), ROM(225), AI(31), AJ(31), BI(31),
3 CMP(3,31), PERC(3,24), UNCMP(3,24,31), AVTEM(3,31),
4 FACT(3,31), II(2), JJ(2), NN(2)
EQUIVALENCE(DWL(1),DWEL(1)), (ROM(1),ROOM(1))
READ INPUT TAPE 5, 1010, ISAT
1010 FORMAT(12)
100 READ INPUT TAPE 5, 1000, TEMP
1000 FORMAT( 24F3.0 )
101 J=-11
102 DO 11 L=1,19
103 J=J+12
104 K=J+11
105 IF(K-22>)11,11,12
12 K=225
11 READ INPUT TAPE 5, 1001, (DWL(I),ROM(I),I=J,K)
1001 FORMAT(12(F4.0,F2.1))
107 READ INPUT TAPE 5, 1006, M,(I,J,N,(W(I,J,N)),K=1,M)
1006 FORMAT(12/(3I2,F5.0))
108 READ INPUT TAPE 5, 1007, M, (I,J,N,(S(I,J,N)),K=1,M)
1007 FORMAT(12/(3I2,F5.0))
109 READ INPUT TAPE 5, 1004, N,( I,J,(HEAT(I,J)),K=1,N)
1004 FORMAT(12/(2I2,F5.0))
```

ISAT=DATE OF FIRST SATURDAY IN MONTH
TEMP=HOURLY TEMPERATURE FOR EACH DAY OF THE MONTH
DWL=NUMBER OF DWELLINGS IN SQ. MILE (AREA SUB-
SCRIPT I VARIES MOST RAPIDLY)
ROM=NUMBER OF ROOMS PER DWELLING
W=WEEKDAY EMISSION RATE FROM AREA I,J FOR THE
N-TH 8 HR. PERIOD OF THE DAY (GR/HR). M=THE
NUMBER OF CARDS
S=SATURDAY EMISSION RATE FROM AREA I,J FOR THE
N-TH 8 HR. PERIOD OF THE DAY (GR/HR). M=THE
NUMBER OF CARDS
HEAT=NUMBER OF GALLONS OF 1 PERCENT SULFUR OIL
USED FOR HEATING (OTHER THAN IN DWELLINGS)
DURING THE MONTH IN AREA I,J

```
110 DO 5 I=1,31
111 DO 5 J=1,3
```

```

5 AVTEM(J,L)=0.0
112 N=0
  DD=0.0
113 DO 128 L=1,31
114 IF(L-(7*N+ISAT))30,31,32
  30 II=1
115 GO TO 33
  31 II=2
116 GO TO 33
  32 II=3
117 N=N+1
  33 DO 6 K=1,24
118 IF(K-8)1,1,2
  1 M=1
119 GO TO 6
  2 IF(K-16)3,3,4
  3 M=2
120 GO TO 6
  4 M=3
  6 AVTEM(M,L)=AVTEM(M,L)+TEMP(K,L)/8.0
121 DO 8 M=1,3
122 FACT(M,L)=(65.0-AVTEM(M,L))/3.0
123 IF(FACT(M,L))7,8,8
  7 FACT(M,L)=0.0
  8 DD=DD+FACT(M,L)
124 AI(L)=II
125 J4=1/II
126 I2=2/II
127 AJ(L)=J4
128 BI(L)=I2
129 DO 10 M=1,31
133 DO 10 N=1,3
  WRITE OUTPUT TAPE 6, 2002, M, N
2002 FORMAT(10HUPDATE-JAN,I3, 9H PERIOD-12)
130 DO 9 J=1,15
131 DO 9 I=1,15
132 RMDL=ROLM(I,J)*DWEL(I,J)
134 E=FACT(N,M)*(RMDL*0.0565+HEAT(I,J)*8.93/DD)
  9 EMISS(I,J,N)=E+W(I,J,N)*AJ(M)+0.5*S(I,J,N)*BI(M)*AI(M)
135 WRITE OUTPUT TAPE 6,2000,((EMISS(I,J,N),I=1,15),J=1,15)
2000 FORMAT(1HP,8F7.0)

  EMISS=HOURLY SO-2 EMISSION RATE FOR EACH AREA
  SOURCE (EMISSION RATES GIVEN FOR PERIODS
  100-800, 900-1700, AND 1800-2400 HRS. AND
  ARE ASSUMED CONSTANT OVER PERIOD)

10 CONTINUE
140 READ INPUT TAPE 5, 1002, ((CMP(I,M),M=1,31),I=1,2)
1002 FORMAT(18F4.0)
141 READ INPUT TAPE 5, 1003, ((PERC(K,L),L=1,24),K=1,3)
1003 FORMAT(24F3.1)

```

READ INPUT TAPE 5, 1111, SULF
1111 FORMAT(F3.2)

CMP=DAILY OIL CONSUMPTION EACH OF M POWER PLANTS
(BBL/DAY)
PERC=PERCENT OF DAILY CONSUMPTION DURING HOUR L
SULF=PERCENT SULFUR IN POWER PLANT FUEL OIL
WRITTEN AS PERCENT

```

142 N=0
  II(1) = 6
  JJ(1) = 8
  NN(1) = 2
  II(2) = 5
  JJ(2) = 9
  NN(2) = 4
143 DO 20 M=1,31
144 IF(M-(7*N+ISAT))21,22,23
  21 K=1
145 DO 16 L=24
  22 K=2
146 DO 16 L=24
  23 K=3
147 N=N+1
  24 DO 20 I=1,2
149 DO 20 L=1,24
20 UNCMP(I,L,M)=PERC(K,L)*CMP(I,M)*29.9*SULF
  DO 150 I=1,2
  DO 150 M=1,31
    WRITE OUTPUT TAPE 6, 2003,I,M
2003 FORMAT(1HPOWER STA-12,10H DATE-JAN.13)
150 WRITE OUTPUT TAPE 6, 2001,(II(I),JJ(I),NN(I),
                           UNCMP(I,L,M),L=1,24)
2001 FORMAT(1HPI2,I2,I1,F8.0)

```

UNCMP=HOURLY SO₂ EMISSION RATE FOR EACH POWER
PLANT (GR/HR)

CALL EXIT
END

APPENDIX 3

GROUND LEVEL CONCENTRATION, IN MICROGRAMS/CUBIC METER,
 AT THE CENTER OF GRID AREA 1, J FOR THE CUMULATIVE
 SULFUR DIOXIDE
 FOR THE 24 HOUR PERIOD ENDING 2400 HOURS 12/26/1965

SOUTH	WEST	J COORDINATE												EAST
		2	3	4	5	6	7	8	9	10	11	12	13	
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	0.	0.	1.	0.	1.	0.	0.	0.	0.	10.	2.	0.	0.	0.
3	0.	1.	1.	1.	1.	0.	0.	15.	18.	0.	3.	0.	0.	0.
4	0.	0.	1.	1.	1.	2.	1.	6.	12.	28.	0.	2.	0.	0.
5	0.	0.	0.	1.	1.	1.	13.	14.	1.	9.	1.	2.	0.	1.
6	0.	0.	1.	0.	2.	7.	8.	17.	29.	12.	2.	17.	0.	0.
7	1.	1.	1.	2.	4.	9.	46.	28.	5.	7.	1.	0.	0.	0.
8	0.	0.	1.	2.	2.	4.	14.	24.	65.	1.	6.	3.	0.	1.
9	1.	1.	2.	3.	18.	1.	10.	109.	19.	4.	2.	1.	5.	0.
10	0.	1.	2.	2.	1.	2.	52.	2.	13.	2.	26.	0.	1.	0.
11	1.	1.	2.	5.	1.	16.	6.	2.	51.	1.	4.	1.	1.	0.
12	1.	1.	0.	3.	1.	22.	3.	5.	5.	0.	4.	6.	0.	0.
13	1.	1.	1.	1.	2.	7.	5.	6.	2.	17.	0.	3.	0.	0.
14	0.	1.	1.	1.	5.	2.	4.	6.	0.	1.	0.	0.	0.	0.
15	0.	0.	0.	0.	3.	0.	1.	3.	0.	7.	4.	0.	0.	0.

hours during which data is missing from 100 hours to end of current period -

GROUND LEVEL CONCENTRATION, IN MICROGRAMS/CUBIC METER,
 AT THE CENTER OF GRID AREA I, J FOR THE CONTAMINANT
 SULFUR DIOXIDE
 FOR THE 24 HOUR PERIOD ENDING 2400 HOURS 17 APRIL 1966

(NORTH)	J COORDINATE																																																	
	WEST			1			2			3			4			5			6			7			8			9			10			11			12			13			14			15			EAST	
1	C.	C.	C.	0.	C.	C.	C.	C.	C.	C.																																								
2	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.																		
3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.																		
4	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.	C.																	
5	0.	2.	0.	1.	0.	1.	0.	1.	0.	1.	0.	1.	0.	1.	0.	1.	0.	1.	0.	1.	0.	1.	0.	1.	0.	1.	0.	1.	0.	1.	0.	1.																		
6	C.	C.	C.	0.	C.																																													
7	1.	1.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.																		
8	C.	C.	C.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.																		
9	0.	0.	0.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.																		
A																																																		
B																																																		
C																																																		
D																																																		
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Y																																																		
Z																																																		
(NORTH)	HOURS DURING WHICH DATA IS MISSING (FROM 100 HOURS TO END OF CURRENT PERIOD) -																																																	
(SOUTH)	0																																																	

GROUND LEVEL CONCENTRATION, IN MICROGRAMS/CUBIC METER,
 AT THE CENTER OF GRID AREA I-J FOR THE CONTAMINANT
 SULFUR DIOXIDE
 FOR THE 24 HOUR PERIOD ENDING 2400 HOURS 1/ 6/1966

(WEEK)	J COORDINATE												(EAST) 15		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	0.	0.	0.	0.	0.	0.	4.	9.	15.	1.	15.	5.	5.	4.	3.
2	0.	C.	0.	0.	0.	C.	8.	11.	26.	37.	13.	35.	9.	C.	C.
3	0.	0.	5.	0.	0.	1.	15.	16.	12.	34.	0.	7.	C.	1C.	7.
4	0.	C.	0.	C.	1.	1.	0.	4.	1.	C.	1.	1.	4.	1.	1.
5	0.	0.	0.	0.	0.	C.	0.	4.	44.	34.	29.	25.	15.	17.	8.
6	0.	0.	0.	C.	3.	C.	0.	C.	2.	6C.	232.	34.	2.	C.	C.
7	0.	0.	0.	0.	0.	1.	C.	82.	2.	1.	35.	C.	53.	23.	6.
8	0.	C.	0.	C.	1.	1.	1.	25.	1.	C.	6.	26.	7.	4.	1C.
9	C.	0.	0.	1.	1.	2.	0.	0.	102.	46.	C.	11.	C.	C.	
A															
T	10	0.	C.	0.	C.	0.	1.	0.	1.	8.	0.	26.	26.	4.	C.
E															
11	0.	C.	0.	0.	0.	0.	0.	0.	0.	2.	8.	0.	C.	3.	5.
12	0.	C.	0.	C.	0.	C.	0.	0.	0.	C.	2.	6.	C.	C.	C.
13	0.	0.	0.	0.	0.	C.	0.	0.	0.	C.	C.	C.	C.	C.	C.
14	0.	C.	0.	0.	0.	C.	0.	0.	0.	C.	0.	C.	0.	C.	C.
15	C.	0.	C.	0.	0.	0.	0.	0.	0.	C.	C.	C.	C.	C.	C.
(SUWTH)															

HOURS DURING WHICH DATA IS MISSING (FROM 100 HOURS TO END OF CURRENT PERIOD) -

0

SECOND LEVEL CONCENTRATION, IN MICROGRAMS/CUBIC METER,
 AT THE CENTER OF GRID AREA I, J FOR THE CONTAMINANT
 SULFUR DIOXIDE
 FOR THE 24 HOUR PERIOD ENDING 2400 HOURS 17 SEP 1966

(WEST)	1	J COORDINATE												(EAST)	
		2	3	4	5	6	7	8	9	10	11	12	13	14	
W	1	0.	C.	0.	C.	C.	1.	0.	0.	C.	C.	C.	0.	0.	0.
	2	0.	0.	1.	0.	1.	0.	0.	0.	35.	C.	C.	C.	C.	C.
	3	0.	1.	1.	1.	2.	0.	14.	17.	22.	0.	0.	0.	0.	0.
	4	0.	C.	1.	1.	1.	8.	1.	6.	30.	6.	C.	C.	C.	C.
	5	0.	C.	0.	1.	1.	7.	61.	44.	0.	29.	1.	0.	0.	0.
	6	0.	C.	1.	0.	3.	9.	26.	145.	1.	26.	2.	4.	C.	C.
	7	0.	C.	1.	2.	3.	5.	67.	92.	35.	16.	1.	1.	0.	C.
R	8	C.	C.	1.	2.	3.	23.	8.	31.	73.	23.	1.	1.	1.	C.
D	9	1.	3.	16.	1.	145.	12.	82.	2.	1.	1.	1.	0.	0.	0.
N	10	0.	1.	2.	3.	0.	40.	49.	6.	76.	1.	5.	C.	1.	C.
A															0.
T															0.
E															0.
	11	1.	1.	2.	2.	15.	6.	3.	2.	53.	1.	1.	1.	1.	0.
	12	1.	1.	0.	6.	1.	12.	1.	1.	9.	C.	0.	C.	0.	C.
	13	1.	1.	C.	1.	1.	4.	1.	13.	1.	1.	0.	0.	0.	0.
	14	0.	0.	0.	1.	1.	C.	6.	12.	0.	1.	C.	0.	C.	0.
(SOUTH)	15	0.	6.	C.	C.	0.	0.	2.	3.	0.	0.	C.	0.	C.	0.

HOURS DURING WHICH DATA IS MISSING (FROM 100 HOURS TO END OF CURRENT PERIOD) -

0

GROUND LEVEL CONCENTRATION, IN MICROGRAMS/CUBIC METER,
 AT THE CENTER OF GRID AREA 1, J FOR THE CONTAMINANT
 SULFUR DIOXIDE
 FOR THE 24 HOUR PERIOD ENDING 2400 HOURS 1/11/1966

(NORTH)		J COORDINATE															(EAST)	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
1	0.	0.	0.	0.	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	0.	0.	C.	1.	0.	1.	0.	0.	0.	0.	25.	0.	0.	C.	0.	0.	C.	
3	0.	1.	1.	1.	1.	1.	0.	0.	0.	10.	42.	0.	0.	0.	0.	0.	0.	
4	0.	0.	1.	1.	1.	1.	1.	1.	1.	3.	28.	0.	0.	0.	0.	0.	0.	C.
5	0.	1.	0.	0.	1.	1.	55.	51.	0.	19.	1.	1.	1.	2.	0.	0.	0.	C.
C	6	0.	0.	1.	0.	1.	4.	24.	28.	21.	14.	1.	1.	2.	0.	0.	0.	
U	7	0.	0.	1.	1.	3.	14.	67.	108.	7.	1.	1.	1.	0.	0.	0.	0.	C.
R	8	0.	0.	1.	1.	2.	1.	6.	22.	99.	4.	0.	C.	1.	0.	0.	0.	C.
D	9	0.	0.	1.	2.	4.	1.	13.	7.	76.	2.	1.	C.	1.	0.	0.	0.	
I	10	0.	0.	1.	2.	0.	1.	36.	3.	58.	1.	0.	C.	0.	0.	0.	0.	C.
N	11	1.	1.	1.	0.	0.	1.	4.	4.	28.	1.	1.	C.	0.	0.	0.	0.	
A	12	1.	1.	0.	1.	0.	8.	4.	11.	7.	C.	0.	C.	0.	0.	0.	0.	
F	13	0.	1.	0.	1.	2.	3.	4.	15.	4.	C.	0.	0.	C.	0.	0.	0.	
E	14	0.	0.	0.	0.	3.	1.	5.	8.	0.	0.	C.	0.	0.	0.	0.	0.	
L	15	0.	0.	0.	0.	0.	0.	2.	3.	0.	0.	C.	C.	0.	0.	0.	0.	
(SOUTH)																		

HOURS DURING WHICH DATA IS MISSING (FROM 100 HOURS TO END OF CURRENT PERIOD) -

0

GROUND LEVEL CONCENTRATION, IN MICROGRAMS/CUBIC METER,
 AT THE CENTER OF GRID AREA I, J FOR THE CONTAMINANT
 SULFUR DIOXIDE
 FOR THE 24 HOUR PERIOD ENDING 2400 HOURS 1/13/1966

HOUR(I)	J COORDINATE	(EAST)													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.	C.	0.	2.	5.	3.	16.	0.	0.	20.	1.	1.	0.	C.	C.
2	0.	1.	1.	0.	6.	16.	11.	5.	C.	C.	1.	C.	C.	C.	
3	0.	C.	0.	6.	7.	13.	43.	36.	1.	2.	0.	C.	1.	C.	
4	0.	C.	1.	3.	1.	28.	5.	16.	0.	2.	1.	C.	C.	0.	C.
5	0.	0.	0.	2.	7.	11.	9.	6.	74.	2.	0.	C.	0.	0.	C.
6	0.	1.	6.	4.	4.	19.	24.	7.	2.	2.	1.	C.	C.	C.	
7	0.	1.	1.	2.	8.	9.	9.	8.	4.	C.	0.	C.	0.	0.	C.
8	C.	C.	0.	2.	2.	1.	1.	39.	5.	3.	C.	C.	0.	C.	
9	C.	0.	1.	1.	2.	0.	6.	4.	5.	C.	0.	C.	0.	0.	C.
10	0.	C.	1.	1.	0.	3.	3.	1.	5.	C.	C.	C.	0.	C.	
11	0.	0.	1.	0.	0.	0.	0.	0.	2.	C.	C.	0.	0.	0.	C.
12	0.	0.	0.	0.	C.	3.	0.	0.	0.	C.	C.	C.	0.	C.	
13	0.	0.	0.	0.	0.	0.	0.	1.	C.	0.	C.	0.	0.	0.	C.
14	C.	C.	0.	C.	C.	0.	0.	0.	C.	C.	C.	C.	C.	C.	
15	C.	0.	0.	0.	0.	0.	C.	0.	0.	C.	0.	0.	C.	0.	C.

HOURS DURING WHICH DATA IS MISSING (FROM 100 HOURS TO END OF CURRENT PERIOD) -

1

GROUND LEVEL CONCENTRATION, IN MICRUGRAMS/CUBIC METER,
 AT THE CENTER OF GRID AREA I,J FOR THE CONTAMINANT
 SULFUR DIOXIDE
 FOR THE 24 HOUR PERIOD ENDING 2400 HOURS 1/16/1966

(NORTH)	1	J COORDINATE												(EAST)	
		2	3	4	5	6	7	8	9	10	11	12	13	14	
1	0.	0.	0.	0.	0.	1.	0.	0.	0.	0.	1.	1.	1.	1.	1.
2	0.	0.	1.	0.	1.	0.	0.	0.	0.	4.	81.	18.	4.	6.	0.
3	0.	1.	1.	1.	1.	0.	1.	0.	11.	3.	31.	0.	4.	3.	
4	0.	0.	1.	1.	1.	1.	2.	1.	16.	13.	2.	13.	1.	0.	
5	0.	0.	0.	1.	1.	21.	29.	23.	18.	8.	6.	5.	8.	1.	
6	0.	0.	1.	0.	1.	2.	10.	14.	122.	278.	69.	14.	2.	1.	
7	0.	0.	1.	1.	1.	3.	7.	8.	29.	9.	112.	1.	13.	10.	4.
R															
D	8	0.	0.	1.	1.	2.	1.	3.	13.	29.	45.	2.	1.	5.	
I															
N	9	1.	0.	2.	2.	9.	1.	4.	159.	26.	36.	14.	8.	18.	0.
A															
T	10	0.	1.	1.	2.	0.	3.	2.	3.	21.	29.	6.	5.	9.	5.
E															
11	1.	1.	1.	0.	0.	1.	2.	2.	36.	11.	19.	1.	1.	4.	3.
12	1.	1.	0.	1.	1.	0.	1.	3.	20.	0.	9.	8.	0.	0.	1.
13	1.	1.	2.	1.	1.	0.	1.	5.	4.	3.	6.	3.	1.	0.	
14	0.	0.	0.	0.	0.	0.	3.	5.	0.	2.	0.	0.	1.	1.	0.
15	0.	0.	0.	0.	0.	0.	2.	3.	0.	0.	0.	0.	0.	1.	1.
(SOUTH)															

HOURS DURING WHICH DATA IS MISSING (FROM 100 HOURS TO END OF CURRENT PERIOD) -

0

GROUND LEVEL CONCENTRATION, IN MICRORAMS/CUBIC METER,
 AT THE CENTER OF GRID AREA I, J FOR THE CONTAMINANT
 SULFUR DIOXIDE
 FOR THE 24 HOUR PERIOD ENDING 2400 HOURS 1/18/1966

(NORTH)		J COORDINATE													(EAST)	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.	0.	0.	0.	1.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	0.	C.	1.	0.	1.	0.	0.	0.	0.	0.	29.	36.	8.	0.	0.	0.
3	0.	1.	8.	1.	1.	1.	0.	0.	0.	0.	0.	40.	0.	3.	2.	2.
4	0.	0.	1.	2.	2.	1.	2.	3.	0.	0.	1.	0.	13.	1.	1.	1.
5	0.	0.	0.	1.	2.	1.	3.	14.	13.	15.	3.	1.	0.	1.	2.	2.
6	0.	0.	0.	1.	0.	2.	4.	4.	3.	9.	106.	170.	26.	1.	0.	1.
7	0.	0.	2.	1.	2.	5.	4.	3.	10.	5.	148.	2.	15.	8.	C.	
8	0.	0.	0.	1.	2.	3.	2.	1.	22.	1.	4.	1.	54.	1.	2.	1.
9	1.	1.	2.	3.	6.	1.	4.	4.	1.	98.	43.	5.	3.	1.	C.	
10	0.	1.	2.	3.	0.	3.	0.	3.	1.	32.	2.	10.	9.	0.	0.	
11	1.	1.	2.	0.	0.	0.	3.	1.	3.	3.	25.	1.	2.	1.	C.	
12	1.	1.	0.	1.	0.	0.	0.	1.	1.	0.	12.	2.	0.	0.	C.	
13	1.	1.	0.	1.	0.	0.	0.	0.	1.	0.	0.	1.	0.	0.	C.	
14	0.	1.	0.	0.	0.	0.	0.	0.	0.	1.	0.	0.	0.	0.	0.	
15	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	C.	
(SOUTH)																

HOURS DURING WHICH DATA IS MISSING (FROM 100 HOURS TO END OF CURRENT PERIOD) -

GROUND LEVEL CONCENTRATION, IN MICROGRAMS/CUBIC METER,
 AT THE CENTER OF GRID AREA 1, J FOR THE CONTAMINANT
 SULFUR DIOXIDE
 FOR THE 24 HOUR PERIOD ENDING 2400 HOURS 1/20/1966

(WEEK)	J COORDINATE														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.	C.	0.	0.	1.	1.	0.	0.	0.	C.	0.	C.	C.	C.	C.
2	0.	0.	1.	0.	1.	0.	0.	0.	0.	13.	0.	C.	0.	0.	0.
3	0.	1.	1.	1.	1.	2.	0.	0.	0.	44.	0.	1.	0.	C.	C.
4	0.	0.	1.	1.	1.	2.	1.	0.	41.	12.	0.	0.	0.	0.	0.
5	6.	C.	0.	1.	1.	2.	97.	68.	1.	34.	1.	1.	2.	C.	C.
6	0.	0.	1.	0.	2.	3.	40.	45.	29.	26.	2.	4.	2.	1.	0.
7	C.	C.	2.	1.	2.	4.	23.	23.	108.	2C.	4.	1.	3.	C.	C.
8	C.	0.	1.	2.	2.	1.	13.	15.	135.	70.	1.	1.	2.	0.	1.
9	1.	1.	3.	4.	1.	10.	70.	128.	1C.	2.	1.	2.	C.	C.	C.
A	0.	1.	2.	3.	0.	1.	6.	8.	102.	5.	12.	1.	2.	0.	0.
T	10	0.	1.	2.	3.	0.	1.	7.	7.	112.	4.	1.	1.	C.	C.
E	1.	1.	2.	1.	1.	1.	6.	10.	66.	1.	0.	0.	0.	0.	0.
11	1.	1.	0.	2.	1.	1.	6.	10.	66.	1.	0.	0.	0.	0.	0.
12	1.	1.	0.	0.	1.	1.	6.	10.	66.	1.	0.	0.	0.	0.	0.
13	1.	1.	0.	1.	2.	C.	5.	35.	34.	6.	C.	C.	C.	C.	C.
14	0.	0.	0.	0.	1.	1.	0.	17.	37.	16.	1.	0.	0.	0.	0.
15	0.	0.	0.	1.	1.	C.	16.	32.	15.	C.	C.	C.	C.	C.	C.
(SUM)															

HOURS DURING WHICH DATA IS MISSING (FROM 100 HOURS TO END OF CURRENT PERIOD) -

GROUND LEVEL CONCENTRATION, IN MICROGRAMS/CUBIC METER,
 AT THE CENTER OF GRID AREA I,J FOR THE CONTAMINANT
 SULFUR DIOXIDE
 FOR THE 24 HOUR PERIOD ENDING 2400 HOURS 1/25/1966

(WEST)		J COORDINATE												(EAST)		
(NORTH)		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.	0.	0.	0.	0.	0.	1.	0.	0.	0.	0.	0.	c.	0.	0.	0.
2	0.	0.	1.	0.	1.	0.	0.	1.	2.	6.	13.	0.	c.	c.	0.	c.
3	0.	1.	1.	1.	2.	2.	0.	6.	15.	30.	0.	0.	0.	0.	0.	0.
4	0.	0.	1.	2.	1.	7.	6.	1.	6.	28.	4.	c.	0.	0.	0.	0.
5	0.	1.	1.	1.	1.	5.	66.	50.	0.	27.	2.	2.	1.	0.	0.	0.
6	0.	0.	1.	1.	4.	21.	45.	68.	14.	26.	2.	1.	2.	c.	c.	c.
7	0.	1.	4.	11.	9.	4.	56.	123.	70.	13.	2.	1.	2.	c.	c.	c.
R	0.	1.	6.	3.	5.	24.	13.	34.	83.	12.	1.	1.	2.	c.	c.	c.
8	0.	1.	5.	14.	24.	6.	86.	18.	79.	5.	1.	1.	0.	0.	0.	0.
I	1.	2.	7.	5.	25.	21.	13.	2.	47.	1.	c.	1.	c.	c.	c.	c.
N	9.	1.	1.	5.	14.	24.	6.	86.	18.	79.	5.	1.	1.	2.	c.	c.
A	10.	0.	8.	4.	10.	3.	42.	98.	4.	76.	1.	1.	c.	1.	c.	c.
T	11.	1.	2.	7.	5.	25.	21.	13.	2.	47.	1.	c.	0.	0.	0.	0.
E	12.	2.	5.	3.	17.	3.	92.	3.	7.	9.	0.	c.	c.	c.	c.	c.
13.	1.	5.	7.	2.	15.	25.	3.	19.	1.	0.	0.	0.	0.	0.	0.	0.
14.	2.	5.	2.	1.	40.	3.	8.	14.	0.	c.	c.	c.	c.	c.	c.	c.
15.	3.	1.	1.	7.	24.	0.	1.	1.	0.	c.	0.	c.	0.	0.	0.	0.
(SOUTH)																

HOURS DURING WHICH DATA IS MISSING (FROM 100 HOURS TO END OF CURRENT PERIOD) - 0

GROUND LEVEL CONCENTRATION, IN MICROGRAMS/CUBIC METER,
 AT THE CENTER OF GRID AREA I, J FOR THE CONTAMINANT
 SULFUR DIOXIDE
 FOR THE 24 HOUR PERIOD ENDING 2400 HOURS 1/27/1966

MONTH	J COORDINATE															(EAST)	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
1	0-	0-	0-	0-	0-	1-	0-	0-	0-	0-	0-	0-	0-	1-	1-	0-	
2	0-	0-	1-	0-	1-	0-	0-	0-	0-	0-	0-	0-	0-	2-	0-	0-	
3	0-	1-	1-	1-	1-	1-	0-	0-	0-	0-	0-	0-	0-	1-	1-	1-	
4	0-	0-	3-	1-	1-	1-	2-	1-	0-	0-	0-	0-	0-	10-	3-	C-	
5	0-	0-	0-	1-	1-	1-	2-	1-	19-	5-	8-	6-	6-	4-	5-	2-	
6	0-	0-	1-	1-	1-	3-	3-	8-	375-	282-	56-	12-	0-	2-	2-		
7	0-	0-	1-	1-	2-	3-	4-	3-	140-	6-	117-	4-	5-	3-	2-		
R										1-	6-	3-	89-	2-	48-	3-	
D	8	0-	0-	1-	2-	2-	1-	1-									
I																	
N	9	1-	0-	2-	2-	9-	0-	2-	473-	1-	51-	18-	7-	18-	3-	0-	
T	10	0-	1-	1-	2-	0-	3-	1-	2-	1-	33-	21-	2-	7-	8-	2-	
E																	
11	1-	1-	1-	0-	0-	1-	2-	1-	42-	11-	33-	4-	1-	4-	6-		
12	1-	1-	0-	1-	0-	0-	0-	1-	26-	C-	15-	15-	0-	C-	3-		
13	1-	1-	0-	1-	1-	0-	0-	0-	6-	10-	1-	8-	5-	1-	1-		
14	0-	0-	0-	0-	0-	0-	0-	0-	11-	2-	1-	3-	3-	1-			
15	0-	0-	0-	0-	0-	0-	0-	0-	5-	4-	1-	1-	1-	2-	3-		
SOUTH																	

HOURS DURING WHICH DATA IS MISSING (FROM 100 HOURS TO END OF CURRENT PERIOD) -

0

GROUND LEVEL CONCENTRATION, IN MICRORAMS/CUBIC METER,
 AT THE CENTER OF GRID AREA I,J FOR THE CONTAMINANT
 SULFUR DIOXIDE.
 FOR THE 24 HOUR PERIOD ENDING 2400 HOURS 1/30/1966

(WEST)		J COORDINATE												(EAST)		
(NORTH)	(WEST)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.	0.	0.	0.	1.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	c.
2	0.	0.	1.	0.	1.	0.	0.	0.	0.	0.	0.	130.	4.	1.	c.	c.
3	0.	1.	1.	1.	2.	1.	1.	0.	0.	0.	0.	0.	55.	c.	1.	c.
4	0.	c.	1.	2.	1.	1.	2.	2.	0.	0.	0.	0.	0.	25.	c.	c.
5	0.	0.	0.	1.	2.	2.	3.	25.	35.	2.	1.	1.	c.	1C.	1.	
6	0.	c.	1.	0.	2.	4.	4.	2.	17.	449.	13.	3.	0.	1.	7.	
7	0.	0.	2.	1.	2.	5.	4.	3.	1.	6.	213.	1.	2.	1.	3.	
R	0.	c.	1.	2.	2.	2.	1.	7.	2.	0.	2.	99.	1.	c.	1.	
D	0.	c.	1.	2.	3.	12.	1.	2.	3.	5.	4.	2.	38.	2.	c.	
I	1.	1.	3.	3.	12.	1.	2.	2.	3.	5.	4.	2.	2.	1.	1.	
N	9	1.	1.	2.	3.	0.	6.	1.	2.	2.	55.	1.	2.	5.	22.	
A	10	0.	1.	2.	3.	0.	6.	1.	2.	2.	55.	1.	2.	5.	22.	
T	11	1.	1.	2.	1.	0.	c.	3.	2.	1.	15.	43.	1.	1.	8.	
E	12	1.	1.	0.	1.	c.	0.	2.	1.	c.	3.	15.	1.	0.	6.	
L	13	1.	1.	0.	1.	1.	0.	0.	0.	1.	0.	c.	2.	12.	2.	
M	14	0.	1.	0.	0.	c.	0.	0.	0.	1.	0.	1.	7.	9.	2.	
(SOUTH)	15	0.	0.	0.	0.	c.	0.	0.	0.	0.	1.	c.	1.	5.	8.	

HOURLS DURING WHICH DATA IS MISSING (FROM 100 HOURS TO END OF CURRENT PERIOD) -

APPENDIX 4

PROGRAM FOR SORTING WIND DATA
FOR USE IN WIND ROSES

```
DIMENSION DIRVEL(2,12), R(2), F(2), SH(2), IWIND(5,17),
1 ISEVEN(16)
1 DO 90 I = 1,5
    DO 90 J = 1,17
90 IWIND(I,J) = 0
    CALM = 0.0
    SUM = 0.0
    CODE = 0.0
2 READ INPUT TAPE 5,4000,LOX,NIX,RSTA,TYR,RMO,RDAY,RHRC,
    RHRL,RHR2
4000 FORMAT(2I2, 7F2.0 )
```

VARIABLE IDENTIFICATION

LOX - A SWITCH, DEPENDENT UPON DIRECTION-SPEED
DATA REQ.

- = 1 IF DIRECTION-SPEED DATA REQ. FOR MONTHLY
PERIOD(S),
- = 2 IF DIRECTION-SPEED DATA REQ. FOR DAILY
PERIOD(S)
- = 3 IF DIRECTION-SPEED DATA REQ. FOR HOURLY
PERIOD(S)
- = 4 IF DIRECTION-SPEED DATA FOR YEARLY
PERIOD(S)

NIX - A SWITCH, DEPENDENT UPON USE OF DATA OR
POSITION IN DATA DECK

- = 1 IF DATA CARD INDICATES 1 THRU N-1 DATA TO
BE INCLUDED IN WIND ROSE (EX. 1ST THRU
5TH MONTHS DATA IF 6 MONTHS OF DATA ARE
TO BE INCLUDED IN WIND ROSE)
- = 2 IF DATA CARD INDICATES LAST (N) DATA TO
BE INCLUDED IN WIND ROSE (EX. 6TH
MONTH DATA IN A 6 MONTH WIND ROSE)
- = 3 IF DATA CARD INDICATES LAST DATA TO BE
PROCESSED IN DATA DECK

RYR,RMO,RDAY,RHRC,RHR1,RHR2, = YEAR,MONTH,DAY,
HOUR, CODE (AM=11,PM=22), AND HOURS
(FIRST AND LAST HOUR, 12 HR. CLOCK,
APPEARING ON DATA CARD FOR WHICH DATA IS
REQUESTED

RSTA = STATION FOR WHICH DATA IS REQUESTED

```

CODE = CODE+1.0
IF(CODE = 1.0)1000,3,4
3 IYR1=RYR
M01=RMO
1DAY1=RDAY
4 GO TO (5, 110, 110),NIX
110 IYR2=RYR
M02=RMO
1DAY2=RDAY
5 DATA = 0.0
6 READ INPUT TAPE 5,4001,STA,YR,HRC,AM0,DAY,DIRVEL,R,F,SH
4001 FORMAT( 35F2.0)

```

IDENTIFICATION OF OBSERVED VARIABLES

STA = STATION OF OBSERVATIONS
 YR,AM0,DAY,HRC, = YEAR,MONTH,DAY, AND HOUR CODE
 DURING WHICH OBSERVATIONS WERE
 MADE

DIRVEL = 12 ONE HOUR WIND DIRECTION-SPEED
 OBSERVATIONS

R, F, SH = HOURS BETWEEN WHICH RAIN, FOG, SMOKE-
 HAZE EXISTED

NOTE**

ALL MONTHS MUST CONTAIN 62 DATA CARDS PER STATION
 IF DATA IS MISSING LEAVE DIRVEL BLANK
 ALL DAYS MUST CONTAIN 2 DATA CARDS PER STATION

```

IF(RSTA = STA)100, 7, 100
1000 WRITE OUTPUT TAPE 6,5000
5000 FORMAT(14H1ERROR IN DATA )
  GO TO 300
  7 IF(RYR = YR) 100, 8, 100
  8 GO TO (9, 9, 9, 15),LOX
  9 IF(RMO = AM0)100, 10, 100
 10 GO TO (15, 11, 11, 15),LOX
 11 IF(RDAY = DAY)100, 12, 100
 12 GO TO (15, 15, 13, 15),LOX
 13 IF(RHRC = HRC)100, 14, 100
 14 M = RHR1
    N = RHR2
    GO TO 160
 15 M = 1
    N = 12
160 DATA = DATA + 1.0
 16 DO 99 J = M,N
    DIR = DIRVEL(1,J)
    IF(DIR = 17.0)17,18,1000
 18 CALM = CALM + 1.0
    GO TO 89
 17 IF(DIR = 1.0)99,21,22
 21 KEY = 1
    GO TO 60

```

```
22 IF(DIR = 5.0)39,24,25
24 KEY = 5
  GO TO 60
39 IF(DIR = 3.0)41,42,40
40 KEY = 4
  GO TO 60
41 KEY = 2
  GO TO 60
42 KEY = 3
  GO TO 60
25 IF(DIR = 9.0)44,27,28
27 KEY = 9
  GO TO 60
44 IF(DIR = 7.0)48,47,45
45 KEY = 8
  GO TO 60
47 KEY = 7
  GO TO 60
48 KEY = 6
  GO TO 60
28 IF(DIR = 13.0)49,30,34
30 KEY = 13
  GO TO 60
49 IF(DIR = 11.0)51,52,50
50 KEY = 12
  GO TO 60
51 KEY = 10
  GO TO 60
52 KEY = 11
  GO TO 60
34 IF(DIR = 15.0)33,36,37
33 KEY = 14
  GO TO 60
36 KEY = 15
  GO TO 60
37 KEY = 16
60 VEL = DIRVEL(2,J)
  IF(VEL = 13.0)62,61,61
61 JAX = 4
  GO TO 70
62 IF(VEL = 8.0)64,63,63
63 JAX = 3
  GO TO 70
64 IF(VEL = 5.0)66,65,65
65 JAX = 2
  GO TO 70
66 JAX = 1
70 IWIND(JAX,KEY) = IWIND(JAX,KEY) + 1
89 SUM = SUM + 1.0
99 CONTINUE
100 GO TO (101, 102, 103, 104),LOX
101 IF(DATA = 62.0)6,104,104
```

```

102 IF(DATA = 2.0)6,104,104
103 IF(DATA = 1.0)6,104,104
104 GO TO (2, 105, 105),NIX
105 CALMAG = CALM/16.0
      CALMUR = CALMAG + 0.5
      MAGCAL = CALMUR
      DO 120 LL = 1,16
120 ISEVEN(LL) = IWIND(1,LL) + IWIND(2,LL) + MAGCAL
      DO 140 NN = 1,4
      DO 140 MM = 1,16
140 IWIND(NN,17) = IWIND(NN,MM) + IWIND(NN,17)
      DO 141 II = 1,16
      DO 141 JJ = 1,4
141 IWIND(5,II) = IWIND(JJ,II) + IWIND(5,II)
      WIND = SUM - CALM
      IWIND(5,17) = WIND
      ISTA = RSTA
      WRITE OUTPUT TAPE 6, 5001,ISTA
5001 FORMAT( 1H1/////////5X, 54H      WIND DIRECTION-SPEED
                           DATA FOR JACKS
                           LUNVILLE, FLORIDA // 10X, 23HWIND RECORDING STATION 12 )
                           GO TO (125, 126, 126, 127),LOX
125 IF(CODE = 1.0)1000,150,151
150 WRITE OUTPUT TAPE 6, 5007, M01, IYR1
5007 FORMAT( 10X, 13HTIME PERIOD 12,3H/19I2 )
      GO TO 130
151 WRITE OUTPUT TAPE 6, 5002, M01, IYR1, M02, IYR2
5002 FORMAT(10X,13HTIME PERIOD 12,3H/19I2,4H TO 12,3H/19I2)
      GO TO 130
126 WRITE OUTPUT TAPE 6, 5003, IDAY1,M01,IYR1, IDAY2,M02,IYR2
5003 FORMAT( 10X, 13HTIME PERIOD 12,1H/12,3H/19I2,4H TO 12,
                           1H/12,3H/19I2 )
      GO TO 130
127 WRITE OUTPUT TAPE 6, 5004, IYR1
5004 FORMAT( 10X, 15HTIME PERIOD 19I2 )
130 WRITE OUTPUT TAPE6,5005,((IWIND(K,L),L=1,17),K=1,5),
      ISEVEN
5005 FORMAT(//28X,52HNUMBER OF HOURS OF WIND IN DIRECTION-
                           SPEED GROU
                           1PS      // 47X,15HWIND DIRECTION/47X,15H-----
                           ----- / 7X,
                           210HWIND SPD. / 8X, 5H(MPH), 5X, 16HN NNE NE ENE,
                           3X, 16HE ESE
                           3   SE SSE, 3X, 16HS SSW SW WSW, 3X, 16HW NW
                           NNW, X,
                           45HTOTAL / 7X, 9H----- // 9X, 3H1-4,3X,4(14,15,15,
                           15), X, 14 //
                           59X, 3H5-7, 3X, 4(14,15,15,15),X, 14 // 9X, 4H8-12, 2X,
                           4(14,15,15,
                           615), X, 14 // 9X, 5H13 OR, X, 4(14,15,15,15), X, 14 /
                           8X, 7HGREAT
                           7ER, // 9X, 5HTOTAL, X, 4(14,15,15,15), X, 14 // 9X, 4H7

```

```
      OR, 2X,  
84(I4,I5,I5,I5,,), / 9X, 4HLESS //// )  
131 WRITE OUTPUT TAPE 6,5006,CALM, CALMAG, SUM  
5006 FORMAT( 7X, 26HNUMBER OF HOURS OF CALM - F4.0 /7X, 48H  
                                MAGNITUDE OF  
1 CALM ORDINATE (HOURS OF CALM/16) - F5.2, 5H HRS. //  
                                7X, 32HTOTAL  
2NUMBER OF HOURS OF DATA - F5.0 )  
300 GO TO (2, 1, 200),NIX  
200 CALL EXIT  
END
```

WIND DIRECTION-SPEED DATA FOR JACKSONVILLE, FLORIDA

WIND RECURRING STATION 2
TIME PERIOD 12/1965

NUMBER OF HOURS OF WIND IN DIRECTION-SPEED GROUPS

WIND SPEED. (MPH)	WIND DIRECTION								NW TOTAL					
	N	NNE	NE	ENE	E	ESW	SE	SSE	SW	SSW	SW	W	WNW	
1-4	72	23	6	26	16	4	2	13	8	7	13	24	26	22
5-7	91	34	2	13	1	0	1	2	6	5	3	3	22	9
8-12	30	15	0	0	0	0	0	0	0	0	2	3	1	5
13 OR GREATER	0	0	0	0	0	0	0	0	0	0	0	0	0	1
TOTAL	193	72	8	39	17	4	3	15	14	14	19	28	53	33
7 OR LESS	165	59	10	41	19	6	5	17	16	14	18	29	50	33
														58
														130

NUMBER OF HOURS OF CALM - 25.
MAGNITUDE OF CALM ORDINATE (HOURS OF CALM/16) - 1.56 HRS.

TOTAL NUMBER OF HOURS OF DATA - 743.

WIND DIRECTION-SPEED DATA FOR JACKSONVILLE, FLORIDA

WIND RECORDING STATION 2
TIME PERIOD 1/1966

NUMBER OF HOURS OF WIND IN DIRECTION-SPEED GROUPS

WIND SPD. (MPH)	WIND DIRECTION												TOTAL		
	N	NNE	NE	ENE	E	EESE	SE	SSE	S	SSW	SW	WSW	W	NNW	
1-4	18	8	8	9	3	5	21	19	20	6	4	14	9	35	15
5-7	108	22	10	6	0	3	9	6	15	15	1	0	12	26	53
8-12	33	18	1	1	0	0	0	5	3	3	0	0	2	27	35
13 OR GREATER	0	3	0	0	0	0	0	0	0	0	0	0	0	5	20
TOTAL	159	51	19	16	3	8	30	30	38	24	5	14	23	93	123
7 OR LESS	127	31	19	16	4	9	31	26	36	22	6	15	22	62	69
														70	

NUMBER OF HOURS OF CALM - 23.
MAGNITUDE OF CALM ORDIATE (HOURS OF CALM/16) - 1.44 HRS.

TOTAL NUMBER OF HOURS OF DATA - 744.

WIND DIRECTION-SPEED DATA FOR JACKSONVILLE, FLORIDA

WIND READING STATION 2
TIME PERIOD 1/1966 (11 DAYS)

NUMBER OF HOURS OF WIND IN DIRECTION-SPEED GROUPS

WIND SPD. (MPH)	WIND DIRECTION											TOTAL						
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW							
1-4	4	0	2	2	0	0	6	0	0	1	0	1	2	14	4	11	47	
5-7	57	12	5	3	0	1	4	4	3	4	0	0	2	11	22	14	142	
8-12	13	5	1	0	0	0	0	0	0	1	0	0	0	1	9	18	7	60
13 OR GREATER	0	3	0	0	C	0	0	0	0	0	0	0	0	1	10	0	14	
TOTAL	79	20	8	5	0	1	10	4	3	6	0	1	5	35	54	32	263	
7 OR LESS	61	12	7	5	0	1	10	4	3	5	C	1	4	25	26	25		

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NUMBER OF HOURS OF CALM - 1.
MAGNITUDE OF CALM ORDINATE (HOURS OF CALM/16) - C.06 HRS.

TOTAL NUMBER OF HOURS OF DATA - 264.

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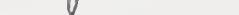
BIOGRAPHICAL SKETCH

John Bernard Koogler was born October 1, 1937, at Akron, Ohio. He attended elementary school and high school in Akron and in September, 1955, he enrolled in the University of Akron. In June, 1960, Mr. Koogler received the degree Bachelor of Science in Civil Engineering. After graduating, he worked as a consulting engineer in Cuyahoga Falls, Ohio, until April, 1961, when he entered the United States Army and trained in a critical skills program. Following his discharge in July, 1961, he resumed his work as a consulting engineer. In February, 1962, Mr. Koogler enrolled in the Graduate School of the University of Florida. In June, 1963, he received the degree Master of Engineering from the Department of Civil (Sanitary) Engineering. From June, 1963, until the present time, he worked toward the degree of Doctor of Philosophy.

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This dissertation was prepared under the direction of the co-chairmen of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Engineering and to the Graduate Council, and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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